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FOREIGN SUBSIDIARIES, INNOVATION AND SPILLOVERS IN THE MANUFACTURING INDUSTRY IN COLOMBIA

DOCTORAL DISSERTATION

PhD candidate:

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This PhD thesis contributes to the analysis of technology internationalization, through foreign direct investment (FDI), and its effects on the competitive and innovation capacities of host countries, paying special attention to developing contexts. In particular, the objective has been to study the effects of FDI on the host technological capabilities through a better understanding of technological strategies of foreign subsidiaries in the Colombian manufacturing industry.

The first issue addressed in this PhD dissertation was the differences in innovation performance of foreign subsidiaries compared to their domestic counterparts. The focus of the research was to assess the differences in innovation input and innovation output of subsidiaries compared to their domestic counterparts and the explanatory factors of these divergences. This quantitative analysis, using cross section data of Colombian manufacturing firms, yielded the following findings:

- Foreign subsidiaries show a superior technological performance than local firms in this country. This allows affirming that the former can be considered as a potential source of knowledge able to generate positive spillover effects.
- Foreign firms use comparatively greater internal and external knowledge inputs to innovate. At the internal level, activities that require intermediate or basic technological capacities predominate, while those knowledge flows within the multinational groups are important as the external side; also, the flow of knowledge taking place with domestic organizations (clients and suppliers, and, to a lesser degree, universities and research centers).
- One result to highlight is that in contrast to prior evidence about the relationship between internationalization and innovation in more developed countries, subsidiaries of multinational firms in Colombia have a similar innovation performance to national firms connected to international markets, i.e. the technology gap of foreign and exporting domestic firms is not so large.

The second analysis pursued was developed thorough three interrelated objectives. The first one was to assess the effect of internal, external and dual sources of knowledge on

the innovation performance of foreign subsidiaries. I have argued that internal and external networks are crucial determinants of the development of distinctive competences in foreign subsidiaries. The second was to study the relationship among these knowledge sources to explain subsidiary´s technological capacities. I postulated that focus only on local or internal context is limited because it is likely that there are interdependencies or trade-off mechanisms between these types of networks, which in turn it may have important implications for the innovation performance of subsidiaries. The third objective was to analyze the role of absorptive capacities in networking capabilities. I proposed that accumulation of firms' absorptive capacities defines a self-reinforcing process with networking activities because own innovation capabilities allow to subsidiaries to exploit external and corporate opportunities to create valuable knowledge.

By using a panel data approach, a first finding was that foreign subsidiaries connected to external and intra-corporate networks have a better innovation performance, both in terms of innovation input as well as the generation of technological innovations. However, the possibility to find subsidiaries that carry out R&D and that are more research intensive, depends much more on their connection to the local innovation system, and specifically, connection with client, suppliers, competitors and R&D organizations with the purpose to innovate. Another finding was that there are significant complementarities between internal and corporate knowledge linkages, suggesting that subsidiaries sometimes combine corporate capabilities with external ones for innovation development. This is opposed the view that the external and corporate embeddedness are merely in conflict with one another or subject to a trade-off between them. Also, absorptive capacities become a key aspect to increase the likelihood of making use of both internal and external linkages.

The third part of the thesis aimed to analyze the effect of the technological heterogeneity of foreign subsidiaries in the generation of intra-industry knowledge spillovers beneficial to domestic owned firms, using firm-level panel data for Colombian manufacturing firms. The analysis was developed in two basic stages. In the first one, an analysis cluster was performed with the aim to identify types of foreign subsidiaries according to their technological responsibilities, i.e., whether they can be classed as creating or exploiting units. In the second stage, I examined the relationship between the productivity of domestic firms and the foreign presence for two types of model specification: (i) the conventional model of spillovers effects in which FDI is simply treated as a homogeneous block and (ii) the subsidiary centered model in which was distinguished the differential effect of types of foreign investment.

Many spillovers models assume that foreign subsidiaries are homogenous. The empirical results confirm our main proposition that competence-creating subsidiaries generate greater positive productivity effects on domestic manufacturing firms, in the same sector, than do units identified as competence exploiting, i.e. creative responsibilities of subsidiaries have a broad explanatory power to understand the possibility that FDI generates positive externality effects. In fact, subsidiaries oriented mostly to technologically exploitative activities do not generate knowledge spillover effects. In contrast, the estimation of the conventional model of spillover effects, where foreign

investment is treated as a homogenous block in terms of technological capabilities, shows that the empirical analysis does not yield statistically significant results; revealing the limitations of considering subsidiaries as a homogeneous group with passive technological behavior, for research and public policy purposes.

Finally, in the fourth part of the research was analyzed the conditional factors that could explain the generation (or absence) of productivity spillovers from foreign investment across regions (provinces) in Colombia, using firm level panel data for manufacturing industries. Also, regional disparities are included in the analysis of the Colombian manufacturing industry. The results permit to demonstrate why technologically active clusters generated over the basis of foreign subsidiaries are not likely in this country. The difference between absorptive capacities at both regional and firm level, as well as the role of industrial specialization, the level of embeddedness and the international connections are key elements to understand spillovers at industry and spatial levels.

SUBSIDIARIA EXTRANJERAS, INNOVACION Y EFECTOS DE LA IED EN LA INDUSTRIA MANUFACTURERA EN COLOMBIA

Tesis doctoral

Candidata a doctorado:

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La tesis doctoral se inscribe en la amplia literatura que busca analizar los procesos de internacionalización de la tecnología, a través de Inversión Extranjera Directa (IED), y su efecto sobre las capacidades competitivas y de innovación de los países receptores, en especial los de menor desarrollo. En particular, su objetivo consistió en estudiar el efecto de la IED sobre las capacidades tecnológicas de las empresas colombianas en el sector manufacturero, a través de una mejor comprensión de las estrategias tecnológicas de las subsidiarias extranjeras que se localizan en ese país.

El primer tema tratado en la investigación fue analizar el desempeño innovador de las subsidiarias de empresas extranjeras en las manufacturas colombianas en comparación con sus contrapartidas nacionales, a través de un análisis cuantitativo usando datos de sección cruzada para las firmas manufactureras en Colombia. Las conclusiones que se desprenden de este estudio son las siguientes:

- Las subsidiarias extranjeras muestran un desempeño tecnológico superior al de las empresas locales en las manufacturas en Colombia, sugiriendo que este tipo de empresas puede ser consideradas como una fuente potencial de externalidades positivas de conocimiento hacia la economía local.
- Las unidades extranjeras hacen un uso relativamente más intensivo de insumos de conocimiento internos y externos para innovar. A nivel interno, predominan las actividades que requieren capacidades tecnológicas intermedias o básicas, como lo es la adquisición de tecnología incorporada y no incorporada. A nivel externo, las subsidiarias extranjeras hacen un uso más intensivo de fuentes externas de conocimiento, especialmente procedente de su grupo multinacional, otras empresas relacionadas en la cadena de producción y en menor grado universidades y centros de investigación.
- En contraste con la evidencia previa sobre la relación entre la internacionalización e innovación, especial en los países más desarrollados (Castellani y Zanfei, 2007, Criscuolo y otros, 2010, Wagner, 2006), las subsidiarias de empresas

multinacionales en Colombia mantienen un desempeño innovador similar al de las empresas nacionales conectadas con los mercados internacionales.

El segundo objetivo de la investigación buscó desarrollar tres propósitos interrelacionados. El primero, analizar el efecto de la conexión de las subsidiarias a fuentes internas (con su corporación multinacional) y externas (con otras empresas, universidades y centros de investigación) de conocimiento sobre su desempeño innovador, bajo el argumento de que las redes que establecen estas unidades son un determinante crucial del desarrollo de competencias distintivas. El segundo, buscó estudiar la relación entre fuentes internas y externas de conocimiento. El argumento principal, es que es limitado concentrarse en sólo en las redes internas y externas por separado, debido a que pueden existir interdependencias o *trade-off* entre los dos tipos de redes; lo que a su vez pueden tener implicaciones importantes sobre el desempeño innovador de las subsidiarias. El tercero, consistió en analizar el papel de la capacidad de absorción de conocimiento de las subsidiarias sobre su posibilidad de establecer vínculos internos y externos para innovar.

Usando una aproximación cuantitativa, a través de modelos de datos de panel, los resultados encontrados indican que los vínculos que establecen las subsidiarias con su grupo multinacional, así como con fuentes externas de conocimiento, tienen un efecto positivo sobre el desempeño innovador de las filiales extranjeras. No obstante, los vínculos externos demuestran ser más importantes que los internos como determinante de las capacidades de innovación de este tipo de empresas. Lo anterior sugiere que las redes de conocimiento son un factor importante para explicar la posibilidad de que las subsidiarias evolucionen hacia mayores responsabilidades creativas, incluso en un país como Colombia cuyo sistema de innovación posee un bajo desarrollo relativo en comparación a otros países más atractivos para ubicar facilidades de investigación por parte de la multinacionales. Otro hallazgo relevante es que los vínculos internos y externos son aspectos complementarios y además las capacidades de absorción de conocimiento son relevantes para explicar la posibilidad de que las subsidiarias extranjeras se encuentran conectadas a fuentes internas y externas de conocimiento.

El tercer objetivo de esta tesis doctoral buscó analizar el efecto de la heterogeneidad tecnológica de las subsidiarias extranjeras sobre la generación de externalidades positivas de conocimiento a través la inversión extranjera, usando datos de panel para la industria manufacturara colombiana. El análisis se desarrolló a través de dos grandes componentes: (i) un análisis clúster con el que se identificaron los tipos de subsidiarias de acuerdo a sus responsabilidades tecnológicas, es decir si pueden ser clasificadas como unidades explotadoras o creadoras de competencias para innovar y (ii) examen de la relación entre la evolución de la productividad de las empresas domésticas y las presencia de inversión extranjera, tratando a las subsidiarias de dos formas: como un bloque homogéneo (modelo clásico de *spillovers*) o como unidades heterogéneas que pueden producir externalidades diferenciadas (modelo centrado en las subsidiarias).

En contraste con los modelos convencionales que asumen que las filiales extranjeras son organizaciones con un comportamiento innovador homogéneo, la investigación permitió demostrar la relevancia de considerar la heterogeneidad tecnológica de las subsidiarias extranjeras para explicar la posibilidad de que existan efectos de desbordamiento de conocimiento de la IED hacia la economía local. En particular, los resultados empíricos confirman que las subsidiarias con mayores responsabilidades creativas son las que tienen mayor probabilidad de generar externalidades positivas hacia las empresas domésticas en el mismo sector industrial.

Por último, el cuarto objetivo perseguido en esta tesis doctoral buscó analizar el efecto de la geografía sobre la posibilidad de que en Colombia existan externalidades positivas de conocimiento desde las empresas extranjeras, utilizando datos de panel a nivel de firma. Una vez se incluye en el análisis las disparidades regionales, los resultados permiten demostrar la baja probabilidad de que en un país de como Colombia se desarrollen clústeres tecnológicamente activos generados sobre la base de las actividades tecnológicas y productivas de las subsidiarias extranjeras. En particular, para comprender las posibles externalidades de la IED a nivel industrial y espacial requiere considerar aspectos como las diferencias en las capacidades de absorción de conocimiento a nivel regional y empresarial, el papel de la especialización industrial de las regiones y el desarrollo de vínculos nivel local y global para generar conocimiento.

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ABSTRACT

The objective of this PhD thesis is to study the effects of foreign direct investment (FDI) on the host countries technological capabilities for getting a better understanding of the technological strategies of foreign subsidiaries in Colombian manufacturing sector and their impact. The aim is to provide new contributions to the existing literature, by using a quantitative approach to the relationship between technology internationalization through FDI and the impact in host locations. The results will also permit to derive some policy implications to promote foreign investment and design better innovation policies to take advantage of the benefits given by technology internationalization. The structure of the dissertation, is composed by a compendium of four interrelated research' papers plus an introductory chapter and a chapter of conclusions and recommendations.

Keywords: foreign subsidiaries, innovation, firms' heterogeneity, networking, embeddedness, technological spillovers, internationalization, Colombia, manufacturing industry and multinationals.

RESUMEN

El objetivo de esta tesis doctoral es estudiar los efectos de la inversión extranjera directa (IED) sobre las capacidades tecnológicas de los países de acogida a través de una mejor comprensión de las estrategias tecnológicas de las filiales extranjeras en el sector manufacturero colombiano y sus repercusiones. El propósito es aportar nuevas contribuciones a la literatura existente, mediante un enfoque cuantitativo para abordar el análisis de la relación entre la internacionalización de la tecnología a través de la IED y su impacto en las economías de acogida. Los resultados permiten asimismo derivar algunas implicaciones políticas de promoción de la inversión extranjera y de fortalecimiento a la innovación que permitan fortalecer y aprovechar los procesos de internacionalización de la tecnología de la economía colombiana. La estructura de la tesis doctoral, está compuesta por un compendio de cuatro artículos de investigaciones, además de un capítulo introductorio y un capítulo de conclusiones y recomendaciones.

Palabras clave: subsidiarias extranjeras, innovación, heterogeneidad, redes, efectos de desbordamiento, Colombia, internacionalización, Colombia, industrias manufactureras y multinacionales.

CHAPTER I. INTRODUCTION

1.1 Motivation

The topics addressed in this thesis dissertation form part of a wide-ranging debate on the consequences and effects of the technology internationalization, through foreign direct investment (FDI), on the competitive and innovation capacities of host countries.

Since the 1970s, the FDI flows have grown at a rate much higher than international trade and production, turning to the multinational enterprises (MNE) in one of the central actors in the globalization process. In order to maintain or increase their competitive advantages, the MNE have gradually modified their strategies to organize their global networks, both in term of production and distribution as well as technology generation (Archibugi & Michie, 1995; Cantwell, 1995; Dunning & Lundan, 2009; Iammarino & McCann, 2013; Laurens et al., 2015). This implies that innovation systems are becoming more integrated in global value networks and more dependent on foreign sources of knowledge (Marin & Arza, 2010; Narula & Dunning, 2000; Pietrobelli & Rabellotti, 2010).

More in detail, three key transformations can be distinguished in the global scene. The first one is the evolution of MNE organization from hierarchical structures toward integrated and heterarquic networks, in which subsidiaries located abroad have a more prominent role in MNE value creation, including innovation activities (Cantwell, 1995; Cantwell & Mudambi, 2005; Cantwell & Piscitello, 2000; Cantwell & Santangelo, 2000; Dunning & Narula, 1995; Florida, 1997; Hedlund, 1994; Pearce, 1999a, 1999b; Zanfei, 2000). As well, the subsidiaries are no longer considered a simple vehicle of knowledge transfer from parent companies to host economies. Nowadays, filial are increasingly playing an active role in the MNE technological development. As a result, they are more integrated to host NIS and are positioned at the core of a multidirectional knowledge flows process inside MNE network (Cantwell & Mudambi, 2005; Dunning & Lundan, 2009; Marin & Arza, 2010; Yang et al., 2008). It is estimated that MNE contribute with half of the world's spending on R&D and about two-thirds of the corporate spending in that same item (UNCTAD, 2005). In 2013, the foreign subsidiaries accounted for about one-third of the business expenditure on R&D in some countries of the OECD, reaching levels above 20% in countries such as France, Germany, the Netherlands and Italy; between 30% and 50% in Canada, Spain, Poland and Sweden; and more than 50% in countries such as the United Kingdom, Austria, Ireland and Slovakia (Dachs et al., 2014).

The second trend is that while the process of technology internationalization has accelerated in recent decades, the evidence shows that the bulk of technological activity is still highly centralized, near the base of origin of the MNE (Cantwell & Santangelo, 2000; Dunning & Lundan, 2009; Iammarino & McCann, 2013; Narula, R. & Zanfei, 2004; Patel & Vega, 1999; Pavitt & Patel, 1999). This is reflected in turn in a high geographical concentration of innovation activities in a few centers of excellence across the world, mainly located in the triad conformed by United States, Europe and Japan. This is due to the fact that MNE technological activities of a greater complexity, related to competence-augmenting strategies, tend to be located in countries with advanced science and technology systems and appropriate institutional conditions to innovate (Archibugi & Michie, 1995; Archibugi & Pietrobelli, 2003; UNCTAD, 2005; Von Zedtwitz & Gassmann, 2002). This implies that while the global generation of innovations is becoming increasingly multipolar is not

necessarily more inclusive; in that sense, there is a growing interest of countries to attract FDI knowledge-intensive activities in order not to be marginalized of international networks of knowledge (Guimón, 2013).

The third trend, visible from the beginning of the last decade, is that the global generation of innovations has also expanded to the developing world, especially toward emerging countries such as China, India and Brazil. In fact, while the business expenditure on R&D accounting for foreign subsidiaries around the world increasing from 13% to 16% between 1996 and 2002, in developing countries this proportion increased from 2% to 18% in the same period; behavior that was accompanied by a growing number of R&D joint ventures, patent applications and licensing of MNE from these countries as well (Athreye & Cantwell, 2007; UNCTAD, 2005). This may be reflecting a new set of economic and technological motivations to relocate part of MNE innovation activities, such as (Mudambi, 2008; Pietrobelli & Rabellotti, 2010; Reddy, 2005; UNCTAD, 2005): (i) the accelerated growth of markets in developing countries; (ii) the increasing flows of foreign investment toward these territories, which causes that part of the innovation activities are transferred to the host economies according with their position in global value chain; (iii) the further fragmentation of corporate R&D at the global level in search of certain segments of those countries in which it is possible to engage efficient and standardized R&D activities and (iv) the upgrading of qualified labor force, engineers and researchers, in combination with lower labor costs in countries that have achieved higher levels of growth and have adopted policies to strengthen their NIS.

Although in the Latin America region FDI flows has contributed to changing the pattern of international insertion with investments in natural resources, export and advanced services (CEPAL, 2016), most countries in the region has been away from the global generation of innovations process led by multinational companies (except for Brazil and Mexico, more recently). However, in recent years there has been a positive change in this aspect. While in the year 2003 FDI projects of high and medium-high technology accounted for 30% all foreign investment in Latin America, in 2015 this share grew up to 60% (CEPAL, 2016) Considering R&D projects, the participation of Latin America has increases from 3.4% in the period 2003-2005 to 6% between 2013 and 2015.

All these transformations have created the need to assess the impact of the increasing of FDI flows and its relationship with the processes of international generation of innovations. In fact, this issue has been gaining greater interest in the field of public policy, due to the importance of design particular policy instruments with the aim to attract intensive R&D foreign investment, and in this way to promote the competitiveness of host countries. Despite the increasing attention in the literature about these topics, the study focus has been concentrated on the role of multinationals in the processes of knowledge transfer only considering one direction relationships with host countries, ignoring the role of foreign subsidiaries to connect global innovation networks and national innovation systems (Marin & Arza, 2010; Narula & Dunning, 2000). That is, is important to recognize that foreign investment is a heterogeneous phenomenon and not all FDI produce the same benefits and opportunities to host countries. There are several factors that could boost or reduce the effect of FDI, such as the entry mode of FDI, the competitive and innovation strategies of multinationals, the evolution of foreign subsidiaries toward more creative responsibilities, the position of subsidiaries in the MNE value chain, the degree of development of national and regional

innovation systems, among others (Birkinshaw et al., 2005; Cantwell & Mudambi, 2005; Carlsson, 2006; Figueiredo, 2011).

Using an econometric approach and microdata for firms, this dissertation thesis aims to fill in some these gaps in the literature, focusing on the case of Colombia; a developing country that in the last thirty years has undergone deep economic and institutional changes that have modified its development pattern and their international insertion. Among them, a substantial increase of FDI flows (both inward and outward), because of structural reforms carried out since the 1990s and the implementation of active policies to attract foreign investors (Reina et al, 2016). In fact, this country is among the top five recipient countries in the Latin American region in the last years (UNCTAD, 2016). At the same time, although this country is not among those economies actively involved in the process of international generation of technology, the contribution by foreign subsidiaries to innovation and R&D investment in manufacturing sector is significant and growing in the last ten years. In fact, while foreign subsidiaries in 2008 accounted for 14.7% of industrial R&D expenditure, for 2012 this share reached around 30%, placing the foreign companies between the major contributors to the generation of innovation capabilities in the industry.

Although Colombia is a country with a long history of inward FDI attraction policies; further technological learning from foreign companies has not been a major policy concern. Until now, political attention has been concentrated on the amount of inward FDI in the national economy, supported in horizontal policies, rather than on the attraction of kind of MNE that contribute with greater value added activities. Also, Colombia is one of the Latin American countries have been less studied in relation to these issues. Although previous studies have investigated the direct and indirect impact of FDI on macroeconomic aggregates, sectors and enterprises (Atallah, 2006; Fedesarrollo, 2007; Hyman, 2011), there are not studies that relates FDI internationalization and innovation. For all this reason, Colombia provides an interesting case study that can contribute to the present state of knowledge about the effects that foreign owned firms may generate on local innovation capabilities in less developed contexts.

1.2 Objectives and hypothesis

One of the main features of the innovation systems in developing countries is their difficulty to produce and exploit the knowledge (Arocena & Sutz, 2000; Viotti, 2002). Due to this, both in innovation and development studies has been recognized the importance for less develop economies to remain open to knowledge and technology created in foreign sites, in a complementary way to the national innovation upgrading (Lundvall, 2010; Narula & Dunning, 2000). Foreign subsidiaries have a strategic position to respond to those challenges, due to their privileged access to several internal and external knowledge bases dispersed around the world (Birkinshaw et al., 2005; Criscuolo et al., 2010; Figueiredo & Brito, 2011; Phene & Almeida, 2008).

Considering developing countries, foreign investment could have the potential to provide to host countries not only a greater access to technological skills generated outside of national innovation systems, but also the possibility to be part of the global processes of creation and dissemination of knowledge (Marin & Arza, 2010; Narula & Dunning, 2000). At the same time, under certain circumstances, inward FDI may exacerbate the technological dependence problems in developing countries and generate unwanted effects, such as crowding-out local firms (Aitken & Harrison, 1999).

Despite of the growing literature that considered foreign subsidiaries as an important source of knowledge beneficial to NIS, there is still many open questions about the role of foreign subsidiaries in host economies, especially in less developing countries. Among others: (i) the conditions that determine the strategies and the technological capabilities of foreign subsidiaries; (ii) the ways in which subsidiaries allow to connect local and foreign sources of knowledge; how they learn from different context and how this is interrelated with more creative responsibilities of subsidiaries in MNE networks and (iii) the conditions that determine the way through which foreign subsidiaries can be an effective source of knowledge spillovers to the host economy. Considering this, the general objective of this PhD thesis is to study the effects of foreign direct investment on host countries technological capabilities through of the understanding of technological strategies of foreign subsidiaries in Colombian manufacturing sector.

To develop the overall objective, four specific objectives are formulated. The first one, is to assess the innovation performance of foreign subsidiaries compared to their domestic counterparts, with the purpose of determining their potential to generate positive effects on the host economy. According to the theoretical predictions and the available empirical evidence it is argued that the technological superiority of foreign subsidiaries over domestic firms can also be expected in the case of Colombia, and that between the factors that could explain the technological superiority of foreign subsidiaries is a more intensive use of internal and external knowledge inputs.

The second objective includes three interrelated purposes: (i) to analyze the effects of technical external and internal linkages on subsidiary´s technological capacities; (ii) to assess the interdependences among internal and external knowledge sources and (ii) to identify the role of absorptive capacities in networking activities. A first aspect proposed is that external, internal and dual linkages are positively related with the innovation performance of foreign subsidiaries. At the same time, there is a self-reinforcing process between internal and external network, i.e. there are complementarities between these two types of sources of knowledge. Finally, subsidiary's engagement in external and internal networks may be conditioned by its previously accumulated capabilities. Empirical analysis to test the hypothesis is done using a panel data of foreign subsidiaries located Colombian manufacturing sector for the period 2008-2012.

The third objective is to explore the role of the technological heterogeneity of foreign subsidiaries (i.e. technology strategies) in the generation of intra-industry knowledge spillovers beneficial to domestic owned firms. The main proposition is that foreign subsidiaries can develop distinctive capabilities by combining resources via own initiative, host-country endowments and internal MNE networks, and these distinctive capabilities may determine the possibility and generation of technological spillover in host economies. The analysis uses firm-level panel data for manufacturing firms in Colombia for the period 2003-2012.

The fourth objective is to explain the generation (or absence) of spillovers across regions (provinces) in Colombia. Here is argued that the presence of more R&D and technology-intense firms is more favorable for the generation of regional spillover effects since this is a signal of higher absorptive capacities to take advantage of the benefits of FDI. The determinants of regional spillovers from FDI if performed using the same panel data for the years 2003 to 2012.

The Table below (Table I. 1) summarizes the objectives, hypotheses, and the methodology used in this Thesis. More details on methodology can be found in the corresponding chapter of each work.

This thesis is divided into fourth further chapters. Chapter II, contains an analyzes of the innovation performance of foreign subsidiaries compared to domestic owned firms using a firm level dataset of Colombian manufacturing firms. The chapter III, explored the effects of technical external and intra-corporate networks on innovation performance of foreign subsidiaries in the Colombian manufacturing sector, as well as the possible interdependences among these knowledge sources to explain subsidiary´s technological capacities. The Chapter IV, analyses empirically the effects of heterogeneous foreign subsidiaries in the generation of knowledge spillovers beneficial for domestic owned firms. The chapter V is an analysis of regional spillovers of FDI. Finally, Chapter VI summarizes the main conclusions, policy implications, limitations to this work and future research opportunities

Table I. 1. Objectives, hypothesis and methodology

Objectives		Hypothesis	Methodology	Publication strategy
General	**Specific**			
To study the effects of foreign direct investment on the host countries technological capabilities through the understanding of technological heterogeneous strategies of foreign subsidiaries in Colombian manufacturing sector	To analyze the innovation performance of foreign subsidiaries in Colombia compared to their domestic counterparts and the factors that could explain the differences in innovation capacities.	-The foreign subsidiaries in the Colombian manufacturing sector are more innovative than national firms. -The innovation superiority of foreign subsidiaries firms can be explained by the fact that they make more intensive use of internal and external knowledge inputs than their domestic counterparts.	-Econometric model using cross section data. Application of a reduced CDM (Crepon et al, 1998) model of innovation input an innovation outputs, to compare the differences in technological strategies between foreign and domestic firms (distinguish between exporting and no exporting firms). -"Innovation accounting" exercise that allows to identify the main factors that explain the knowledge production differences between foreign and domestic firms (Criscuolo et al., 2010)	*GCG Georgetown University – Universia*, 11 (2), 2017
	-To explore the effects of technical external and intra-corporate networks on innovation performance of foreign subsidiaries in the Colombian manufacturing sector. - To assess the interdependences among internal and external knowledge sources to explain subsidiary´s technological capacities.	-Technical linkages with external sources of knowledge are positively related to innovation performance of foreign subsidiaries. - Technical linkages with internal sources of knowledge (parent companies and other MNE subunits) are positive (negatively) related to innovation performance of foreign subsidiaries. - Simultaneous technical linkages with external and internal sources of knowledge are positively related to innovation performance of foreign subsidiaries. - Technical linkages with external sources of knowledge are related positively with internal networks. - A greater absorptive capacity of foreign subsidiaries affects positively the probability to be engaged in internal and external networks.	Two econometric analysis using panel data (2008-2012): 1) Estimation of the likelihood of investing in R&D, the R&D intensity and innovation variables, where networking indicators are included as regressors. 2) Analysis of the likelihood that subsidiaries establish internal, external and dual linkages, as well as the role of absorptive capacities.	*International Business Review* (under review process)

	To explore the effect of the technological heterogeneity of foreign subsidiaries in the generation of intra-industry knowledge spillovers beneficial to domestic owned firms in Colombia.	More creative subsidiaries generate greater positive host country spillover effects, in the same sector, than subsidiaries that only exploit the competences centrally generated in the multinational corporation.	1) Analysis cluster to identify types of affiliates according to their technological responsibilities (classed as creating or exploiting units). 2) Econometric model with panel data to estimate total factor productivity (TFP), through Levinsohn and Petrin method. 3) Analysis of determinants of TFP of domestic firms, including measures foreign presence by types of FDI.	*Research policy* (under review process)
	Explain the generation (or absence) of spillovers across regions (provinces) in Colombia	-The presence of more R&D and technology-intense firms is more favorable for the generation of regional spillover effects since this is a signal of higher absorptive capacities. -In developing context, it is more likely that spillover effects take place in more technological advanced regions because this would favor a higher level of foreign firm's embeddedness as well. -More competitive (less concentrated or oligopolistic) industries make more likely the generation of spillover effects. -Those more internationalized firms –those with higher international connections- are better prepared for the absorption of spillovers, reason why these are more likely in domestic exporting firms.	1) Econometric model with panel data to estimate total factor productivity (TFP), through Levinsohn and Petrin method. 2) Analysis of determinants of TFP of domestic firms, including measures regional foreign presence.	*Journal of Economic Geography* (Under review process)

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CHAPTER II. A COMPARATIVE ANALYSIS OF THE INNOVATION PERFORMANCE BETWEEN FOREIGN SUBSIDIARIES AND OWNED DOMESTIC FIRMS IN COLOMBIAN MANUFACTURING SECTOR

2.1 Introduction

The positive behavior of flows of foreign direct investment (FDI) in recent decades has been accompanied by a substantial increase in the participation of developing countries, mainly Asian and transition economies, but also, to a lesser extent, Latin American and Caribbean countries. Although the innovation activities of multinational enterprises (MNE) still show a high concentration into the developed home countries, since the mid-1990s there has been an expansion into developing countries as well (Laurens et al., 2015; UNCTAD, 2005).

The traditional literature about the effects of foreign direct investment is based on the assumptions of a technological superiority of the foreign subsidiaries over their domestic counterparts (Blomström & Kokko, 1998; Crespo & Fontoura, 2007). This superiority is revealed in the productive advantages of MNE and in the superior innovation capacity of foreign subsidiaries (Bellak, 2004; Castellani & Zanfei, 2007; Criscuolo et al., 2010; Siedschlag & Zhang, 2015; Silva et al., 2013). Empirical studies in more developed countries generally support the hypothesis of the technological superiority of foreign subsidiaries, while the evidence from developing countries tends to be more heterogeneous. In Colombia, the most relevant contributions about the innovation behavior of foreign firms include foreign ownership as a control variable to explain innovation in manufacturing industry, e.g. Langebaek & Escobar (2007), Arbeláez & Parra (2010) and Gallego et al. (2015).

In this paper we analyze the innovation performance of foreign subsidiaries in Colombia compared to their domestic counterparts and the factors that could explain the differences in innovation capacities. Our hypothesis is that subsidiaries are superior in the knowledge production (innovations) over domestic firms and this superiority is because they make a more intensive use of internal and external knowledge inputs. For this purpose, we use a structural model that compares the technological differences between foreign subsidiaries and national firms, which is organized through three analytical blocks: (i) the decision to invest in innovation activities; (ii) the firm efforts made in these investments and (iii) innovation outputs.

The results validate our hypothesis about technological superiority of foreign subsidiaries over domestic firms; in particular, in relation to the intensity in the use of innovation inputs and outputs with a greater degree of novelty and patenting. However, we find that is low the technological gap between foreign subsidiaries and national exporting firms. In comparison with the previous evidence from more developed countries, there are similarities but also differences in the factors that determine the innovation capacity of subsidiaries; particularly, the type and the intensity of the innovation activities.

The following section presents the conceptual framework and the development of our hypothesis. In the third section, we describe the methodology and the data source. In the fourth section, we show and discuss the results obtained. In the fifth section, we present some concluding remarks.

2.2 Theoretical and empirical background

Several studies have attempted to explain the relationship between firms' internationalization through FDI and innovation capabilities. Although a traditional motivation of R&D investment in subsidiary firms is the need to adapt products and processes to host markets (Mansfield et al., 1979), the growth in FDI and the strong dynamic of technological change in the last thirty years, have generated modifications in multinational business strategies, aimed at a higher diversification of their technological competencies to absorb and combine geographically disperse knowledge and capacities. The fact is that MNE have evolved toward greater integration through international networks and less hierarchical corporate structures, in which subsidiaries acquire a more active role in innovation activities (Cantwell, 1995; Hedlund, 1994; Iammarino & McCann, 2013). The multinationals are also increasingly more active in establishing technological alliances with foreign companies and organizations to develop new technologies (Castellani & Zanfei, 2007; Reddy, 2005).

But not all subsidiaries develop the same technological and innovation capacities abroad. This depends on global multinationals strategies, the own evolution of the subsidiaries in time, the specific localization advantages and the sectoral technological opportunities (Balcet & Evangelista, 2005; Birkinshaw & Hood, 1998; Cantwell & Mudambi, 2005; Dunning & Lundan, 2009).In fact, the literature distinguishes two types of subsidiaries according to their technological responsibilities within a multinational group (Cantwell & Mudambi, 2005; Kuemmerle, 1999): (i) competence exploiting subsidiaries, and (ii) competence creating subsidiaries. In the former, innovation activities are generally directed toward adapting products and processes to local markets, while the latter seek the creation or acquisition of new or complementary technological competencies that increase the knowledge stock and innovation capacity of the MNE, for both local and global markets. Knowledge generation activities of the adaptive type are generally more common in subsidiaries located in developing countries (Kuemmerle, 1999), where is possible to find subsidiaries that do not undertake any technological activities or with lesser innovation impacts, as for example the investment in incorporated technology (Marin & Bell, 2010).

Concerning the relationship between innovation and firms' internationalization, a first point of reference is the empirical evidence about the superior productivity levels of multinationals and exporting firms, compared to non-exporter domestic firms (e.g. Doms & Jensen, 1998; Helpman et al., 2004) .According to this literature, multinationals and exporting firms possess productivity advantages that allows them to compete under better conditions in external markets and could explain the technological gap observed between them and not internationalized firms (Bellak, 2004).

A more recently literature, has gone beyond productivity and include explicit measures of innovation inputs and outputs to assess the innovation performance of subsidiaries. In these works, the differences in productivity between subsidiaries (whether national or foreign) and domestic firms is explained by the differences in knowledge production and the greater learning capacity of subsidiaries, because of their global engagement (Castellani & Zanfei, 2007; Criscuolo et al., 2010). The greater integration of subsidiaries in the multinational group, confers to them more innovation potential because each unit of the group learns from the environment in which it operates and transmits that knowledge within the corporation (Frenz & Ietto-Gillies, 2007). The evidence in fact

shows that the degree of integration of subsidiaries within their multinational group is one of the main determinants of their superior innovation behavior in developing countries (Marin & Bell, 2010).

There are two main approaches to assess the innovation performance of subsidiaries. The first one focuses on the identification of patterns of innovation strategies in subsidiaries, without considering the comparison with local firms (e.g. Balcet & Evangelista, 2005; Bas & Sierra, 2002; Cantwell & Mudambi, 2005; Marin & Bell, 2010). The second one refers to the contributions that include the type of firm (i.e. foreign or domestic) as explanatory variables in models of the determinant actors of innovative behavior, comparing the level and significance of their estimated effects (e.g. Criscuolo et al., 2010; Frenz & Ietto-Gillies, 2007; Sadowski & Sadowski-Rasters, 2006). Following this line, we find a group of contributions that use the Crépon, Duguet and Mairesse model (1998, henceforth CDM), to assess the innovation performance of foreign subsidiaries, which permits the correction of endogeneity problems in the estimation of the determinants of innovation and the sample selection biases that characterize the data from innovation surveys (e.g. Dachs et al., 2008; Masso et al., 2012). In addition, some works have used other techniques to identify those factors that better explain the differences in knowledge production between foreign and domestic firms: (i) the propensity score matching method, a technique that allows the comparison of innovative differences between a target group (i.e. subsidiaries) and a control group (i.e. domestic firms)(Falk, 2008); and (ii) the innovation accounting technique, proposed by Mairesse & Mohnen (2002), that allows to explaining the differences between innovation outputs according to firms types and the contribution of multinationality to innovation (Criscuolo et al., 2010).

The empirical evidence about technological superiority of foreign subsidiaries is mixed, in both developed and developing economies. In Scotland, it has been found that foreign ownership has a positive impact on the probability of achieving product innovations in manufacturing industry (Love et al., 1996). In a similar way for United Kingdom, Frenz & Ietto-Gilles (2007) found that the greater propensity to invest on innovation activities in foreign subsidiaries occurs when they undertake innovation activities on an ongoing basis.

In Nordic countries, Dachs et al. (2008) find that there is no difference in the propensity and intensity to undertake R&D, but the subsidiaries produce more innovations and have higher levels of cooperation with other organizations in the national system of innovation. In contrast, foreign subsidiaries in Estonia have more intensive investment in innovation activities but lower capacity to produce innovation outputs (Masso et al., 2012). Sadowsky & Sadowsky-Rasters (2006)found that foreign subsidiaries in the Netherlands are more innovative than domestic firms, although predominate imitative innovations (new for the firm) over “radical” innovations (new for the international market).For United Kingdom, Criscuolo et al. (2010)obtained that firms with global engagement (multinationals and exporters) innovate more than domestic firms, which is du e to their intensive use of knowledge inputs (R&D)and to their greater capacity for learning from global and local knowledge networks. Moreover, the relative importance of each knowledge source in subsidiaries varies with the type of innovation, whether patent or technological innovation. Castellani & Zanfei (2007) had similar findings for the case of Italy, as did Wagner (2006) for Germany, Silva (2013) for Portugal and Siedschlag and Zhang (2015) for Ireland. Empirical evidence with a panel of manufacturing Spanish firms confirm that exporting firms tend to introduce more product innovations and get more patents (Salomon & Shaver, 2005), and Casillas et al. (2015)

found that different forms of knowledge and learning interact to shape the pace of internationalization for a small sample of firms in Spain, in addition to the expected direct effects of learning.

For Latin America countries, there have few studies about subsidiaries innovation performance or the impact of foreign ownership on innovation. According to Alvarez (2001), in Chile, exporting is more significant than foreign ownership in explaining innovation performance. They also find that foreign ownership is not associated with more R&D and with technological innovations (product and process), but foreign investment affects the probability of introducing marketing and design innovations. Alvarez& Robertson (2004) had similar findings for Mexico: while exporting affects most of the innovation measurements, foreign ownership only affects process innovations and the acquisition of licenses. For the same country, Brown and Guzmán (2014) found that foreign investment affect the propensity to innovate and the innovation effort as well as the generation of product and process innovations. Also, Araújo et al. (2015) show the existence of learning by exporting effects in the case of Brazilian manufacturing firms in the period 2006-2008.

In a set of interrelated works for Latin America countries, that used the CDM model (Crepon et al., 1998), it has been found that efforts in innovation are weakly related to foreign ownership. In the cases of Argentina, Chudnovski et al. (2006) showed that foreign ownership is not associated to the propensity to do innovations activities, innovation investment intensity and innovation outputs. Arza & López (2010) confirm this result, although the effect of foreign ownership is positive and significant in the case of process innovation. Minority foreign ownership in Uruguay does not increase the propensity to undertake innovation activities and their effect on the innovation intensity is negative (Cassoni & Ramada, 2010). For Peru, Tello (2015) found that foreign firms show a higher probability of producing non-technical innovation only in high-tech sectors, but do not found a significant impact in technical innovation (i.e. product and process). Finally, Arbeláez &Parra(2011) found that the presence of foreign capital in Colombia does not affect the probability that a firm engages in R&D, but is associated with greater spending on innovation and a greater probability of obtaining radical innovations. For the same country, a similar result is found for Gallego et al. (2015).

Given this literature, review two interrelated hypotheses are proposed here. The theoretical predictions and the available empirical evidence indicate that the technological superiority of foreign subsidiaries over other types of firms can also be expected in the case of Colombia. Based on this, the first hypothesis is the following:

> *Hypothesis 1: The foreign subsidiaries in the Colombian manufacturing sector are more innovative than national firms.*

Following Criscuolo et al (2010), the second hypothesis is defined in relation to the factors that explain the technological superiority of foreign subsidiaries. In particular, we address the argument that there is a positive relationship between firms' internationalization and innovation capacities, the second hypothesis is defined as follows:

Hypothesis 2: The innovation superiority of foreign subsidiaries firms can be explained by the fact that they make more intensive use of internal and external knowledge inputs than their domestic counterparts.

2.3 Methodology

2.3.1 Empirical model

We developed a comparative analysis of the innovation performance between foreign owned subsidiaries and domestic firms, combining the methodological approximation proposed by Criscuolo et al (2010) and the application of a reduced CDM model. Particularly, we estimate the innovation investment and knowledge production function (KPF) equations, excluding productivity analysis. The CDM model attempts to correct two main econometric problems: (i) selection bias which is associated with the fact that only a small number of firms make or report innovation investment (Griffith et al., 2006) and (ii) endogeneity problems, given that innovation expenditures are endogenous in the KPF.

Unlike the original CDM model, and following contributions of Bogota Manual to measure innovation (Jaramillo et al., 2000), we consider a broad range of technological activities and not only expenditures on R&D and total innovation investment, such as intramural and extramural R&D, incorporated technology (i.e. capital goods as machinery and equipment) and unincorporated technology (technology transfer, licenses and technical assistance). This allows us to make a more suitable comparison of the differences in the technological strategies between foreign and domestic firms. Another of the variations is the distinction between domestic exporting and non-exporting firms, which adds greater robustness to the analysis because allows comparing foreign subsidiaries with firms that are technologically more similar to them (i.e. exporter)[1].

The general model is a system of four equations in which Equation0 represents the efforts of firms in innovation activities, i =1,…N being the sub-index relative to firms:

$$g_i^* = \beta_0 x_{0i} + \varepsilon_{0i} \qquad (Equation0)$$

where,$g_i^*$is a latent unobserved variable, x_{0i} is the vector of determinants of innovation efforts, β_0 is the vector of parameters of interest, and ε_{0i} is the error term. Give that equation 0 cannot be estimated directly, the innovation effort (g_i^*) is approximated through the innovation investment, which is denoted byg_i, only if the firm makes or reports such expenditures. Consequently, the following equation describes whether or not firms invest in innovation activities:

$$g_i = \begin{cases} 1 & \text{si } \ g_i^* = \beta_1 x_{1i} + \varepsilon_{1i} > c \\ 0 & \text{si } \ g_i^* = \beta_1 x_{1i} + \varepsilon_{1i} \leq c \end{cases} \qquad (Equation1)$$

where g_i is a dummy variable equal to 1 for firms that report positive innovation investment, and equal to 0otherwise; g_i^* represents a decision criterion to carry out innovation activities, for example, the invest expected return - which should be greater than a threshold $c$for the firm that decides to invest in these activities; $x_{1i}$is the vector of explanatory variables that influence the

[1] The study has one important limitation: the lack of information to identify –domestic- Colombian multinational subsidiaries to compare more appropriately the innovation performance of foreign subsidiaries.

decision to invest in innovation activities (among these, be a foreign subsidiary),β_1 is the vector of the parameters to be estimated and ε_{1i} is the random error terms.

The following equation refers to innovation effort of firm i, conditioned to the firm report a positive innovation investment:

$$k_i = \begin{cases} k_i^* = \beta_2 x_{2i} + \varepsilon_{2i} & \text{si } g_i = 1 \\ 0 & \text{si } g_i = 0 \end{cases} \quad (\textit{Equation 2})$$

where k_i is the logarithm of innovation investment (defined as the ratio of innovation expenditures to the number of employees), x_{2i} is the vector of determinants of innovation effort, β_2 is the vector of the parameters to be estimated and finally ε_{2i} is the error term. Assuming that the errors ε_{1i} andε_{2i} correlated in Equations 1 and 2 and follow a normal distribution, these two equations are estimated jointly through a Heckman selection model (Heckman, 1979). Table II. 1 shows the vector of explanatory variables (x_{1i} y x_{2i}), including the type of firm, whether foreign subsidiary, domestic exporter or domestic non-exporter. Detailed description of dependent variables can be found in Appendix 1. Finally, the last equation is the KPF, which describes the process of transformation of innovation inputs into innovation outputs:

$$t_i = \gamma \hat{k}_i + \beta_i x_{3i} + \varepsilon_{3i} \quad (\textit{Equation 3})$$

Here refers to changes in the knowledge stock proxied by three innovation indicators and $\widehat{k}_i$ is the predicted innovation effort from *equation 2*, conditional to undertaking innovation activities, which corrects the possible endogeneity of innovation investment in the KPF. The coefficient γ represents the elasticity of innovation output with respect to innovation input. The vector of variablesx_{3i}, are the factors that influence knowledge production, β_i is the vector of parameters of interest associated with the remaining explanatory variables and $\varepsilon_{3i}$is the error term.

Table II. 1 Explanatory variables of equations 1 y 2

	Explanatory variables
x_{1i}	-Foreign subsidiary -Domestic exporting firm -Domestic non-exporting firm (reference) Control variables: -Firm size -Innovation protection -Public support -Industrial sector
x_{2i}	-Foreign subsidiary -Domestic exporting firm -Domestic non-exporting firm (reference) Control variables: -Public support -Innovation protection -Innovation cooperation -Internal and external knowledge sources (group, vertical, horizontal and R&D organizations) -Industrial sector

To estimate $t_i$we use diverse measures of innovation, which ensures greater robustness for the analysis and allows to overcoming possible measurement errors. We considered the following indicators:

- Incremental innovation: firms that innovate new or significantly improved goods or services for the same firm or the national market (Duguet, 2006).
- Radical innovations: firms obtain new or significantly improved goods or services for the international market (Duguet, 2006).
- Patenting: firms that have sought or obtained patents in the period analyzed.

Given that all the regressors are dichotomous variables, we use a maximum likelihood probit model to estimate the KFP (Long & Freese, 2006). Following Criscuolo et al. (2010), to have a more comprehensive analysis of the explanatory factors that explain the innovation output differences between foreign subsidiaries and domestic firms, we organized the vectors of explanatory variables (x_{3i}) into the following four groups variables (Table II. 2): (i) type of firm; (ii) knowledge inputs ($\hat{k}_i$); (iii) knowledge flows from internal and external sources, measured through innovation cooperation with other organizations, and (iv) the remaining variables that can influence the production of innovations according to the CDM model.

Table II. 2 Explanatory variables of equation 3

	Group	**Explanatory Variables**
I	Type of firm	-Foreign subsidiary -Domestic exporting firm -Domestic non-exporting firm (reference)
II	Knowledge inputs	-Model 1 (M1): predicted R&D intensity -Model 2 (M2): predicted innovation activities intensity -Model 3 (M3): predicted intensity of the four types of innovation activities separately (Intramural R&D intensity, extramural R&D intensity, incorporated technology intensity and unincorporated technology intensity)
III	Knowledge flows	-Group cooperation -Vertical cooperation -Horizontal cooperation -Cooperation with universities and R&D centers
IV	Control variables	-Firm size -Public support -Innovation protection -Industrial sector

To identify the differences between foreign and domestic firms (reference group) in knowledge production, we first estimate t_i with the variables that indicate the type of firm (Group I) and the control variables (Group IV) to test whether multinationals generate more knowledge outputs than domestic firms do. Secondly, if it is confirmed that multinationals generate more innovation outputs, the knowledge inputs variables are added (Group II). Finally, we add knowledge flows variables (Group III) to determine if the residual variation is explained by the presence of foreign capital. It should be noted that the estimated coefficient for the variable "foreign subsidiary" (i.e.

marginal effect) captures the differences in innovation performance among subsidiaries and exporting and non-exporter domestic firms.

Then we made an "innovation accounting" exercise that allows us to identify the main factors that explain the knowledge production differences between foreign and domestic firms (Criscuolo et al., 2010). This methodology proposes that the differences in innovation output among periods of time of units or firms can be the result of changes in the factors that determine innovation plus a residual called "innovativeness", similar to "productivity" (Mairesse & Mohnen, 2002)[2]. As with the case of Total Productivity Factors (TPF), this residual can be associated with omitted factors such as business performance, organizational competences, cultural issues or environmental factors; although it can also be due to specification errors. This exercise is conducted only when the foreign firm status has a statistical and significant effect on the measures of innovation that we are considered in the estimation.

2.3.2 Data

The firm level database used in the empirical analysis is obtained from the merge of the fourth Development and Technological Innovation Industrial Survey (EDIT, for its acronym in Spanish) and the Annual Manufacturing Survey (Encuesta Anual Manufacturera, henceforth EAM), both collected by the National Administrative Department of Statistics (DANE). The former follow the conceptual guidelines of Oslo and Bogota Manual and its purpose is to characterize innovation activities in Colombian manufacturing sector. This survey provides information from 2007 and 2008 and is applied to the firms included in the company directory used in EAM. The second is a survey of industrial establishments with ten or more employees or with a level of production higher than the value stipulated for each year as a reference and provides general economic data on firm characteristic and performance variables. Merging these two databases we obtained 7,069 observations of which 476 are foreign subsidiaries, 1,692 are domestic exporting firms, and 4,901 are domestic non-exporting firms[3].

Although actually are available the seventh version of the EDIT (2013-2014), we opt to use the data for 2007-2008 for several reasons: The first one is our objective to analyze innovation performance of foreign subsidiaries prior to the economic crisis that reduced significantly FDI flows into developing countries; secondly, to capture the moment and effects of the significant growth of foreign investment toward manufacturing sector in Colombia, which can be attributed to policy reforms made in 2002 for attracting higher FDI (Fedesarrollo, 2007); and third, because these data allow us to compare the results with the prior evidence for Colombia that also uses data for the same period or earlier (Arbelaez & Parra, 2007; Garrido et al., 2015).

Although foreign subsidiaries are only 6.6 per cent of the manufacturing firm, they contribute significantly to industrial aggregates such as sales, employment and industrial R&D and innovation investment (Table II. 1).

[2]Innovation can be understood as the ability or capacity to convert innovation inputs into innovation outputs.

[3] The sample used in the analysis includes all firms and not just innovative ones (Griffith et al., 2006). This is because the design and application of the innovation survey for Colombia follows the Bogotá Manual in terms of the importance of identifying "innovation effort" of firms independent of their success at innovation (Jaramillo et al., 2000).

Table II. 3 Contribution of foreign subsidiaries to industrial aggregates (in %)

	Foreign subsidiaries	Domestic exporting firms	Domestic non-exporting firms
Firms	6,6	23,0	70,4
Sales	33,1	43,00	23,9
Employment	23,8	40,2	36
I&D investment	23,1	51,2	25,7
Innovation investment	30,3	46,8	22,9

Source: Own calculation based on EDIT IV and EAM (DANE)

Table II. 4 shows the average of the main variables of the model by type of firms and the correlations among the variables are presented in Appendix 2. In these measures, foreign subsidiaries are superior to the other firms, providing a preliminary indication that there are differences between foreign and domestic firms in their innovative capacities. However, we observe that the differences between foreign subsidiaries and domestic exporting firms are not as wide as expected.

Table II. 4. Comparisons of innovation inputs, innovation outputs and knowledge flows (on average)

Indicator	Foreign subsidiaries	Domestic exporting firms	Domestic non-exporting firms
Innovation inputs: probability			
R&D (% firms)	20.6	17.0	7.5
Intramural R&D (% firms)	19.5	15.7	6.8
Extramural R&D (% firms)	5.9	4.3	1.9
Incorporated technology (% firms)	52.5	47.5	30.4
Unincorporated technology (% firms)	23.9	17.3	9.2
Innovation activities investment (% firms)	57.1	51.4	33.7
Innovation inputs: innovation effort			
R&D intensity*	512	401	223
Intramural R&D intensity*	425	348	190
Extramural R&D intensity*	86	53	33
Incorporated technology intensity*	6,607	4,099	1,680
Unincorporated technology intensity*	1,161	2,221	96
Innovation activities intensity*	8,993	5,177	2,185
Innovation outputs			
Incremental innovation (% firms)	42.6	38.7	25.1
Radical innovation (% firms)	13.9	12.1	1.6
Patenting (% firms)	4.6	2.4	1.0
Knowledge flows			
Group	16.4	8.3	3.1
Vertical	26.7	24.6	12.2
Horizontal	3.8	3.0	2.0
Universities and R&D centers	12.6	11.8	4.3

Source: Own calculation based on EDIT IV and EAM(DANE)
*Values in thousands of pesos at 2008 prices.

2.4 Results

2.4.1 Innovation inputs

Table II. 5 shows the results of the estimation of the engagement in innovation activities and innovation intensity equations. We report marginal effects at the sample mean[4]. Given that the *Rho* estimator in all the estimations is statistically significant it is appropriate to use the Heckman selection method. The first result to highlight is that foreign subsidiaries do not have a higher probability of investing in R&D and innovation activities than domestic firms, especially compared to national exporting companies. At a more disaggregated level, subsidiaries have a higher probability of investing in intramural R&D and unincorporated technology than domestic firms. Although, in the case of intramural R&D, the estimated marginal effects are lower than the level revealed by domestic exporting firms.

Table II. 5. Estimation innovation input equations

Tipo de actividad		Foreign subsidiaries	Domestic exporting firms	Rho	Wald chi2
R&D	Probability	0,021	0.040***	0.848***	78.4***
		(0,014)	(0,009)		
	Intensity	0.535**	0.370***		
		(0,235)	(0,139)		
Intramural R&D	Probability	0.026*	0.040***	0.859***	77.2***
		(0,014)	(0,009)		
	Intensity	0,337	0.382***		
		(0,240)	(0,146)		
Extramural R&D	Probability	0,002	0,004	1.199***	33.7***
		(0,006)	(0,004)		
	Intensity	0.917**	0.453*		
		(0,493)	(0,270)		
Innovation activities	Probability	0,027	0.066***	0.636*	222.1***
		(0,026)	(0,016)		
	Intensity	0.626***	0.309***		
		(0,119)	(0,068)		
Incorporated technology	Probability	0,024	0.064***	0.740*	117.2***
		(0,026)	(0,015)		
	Intensity	0.508***	0.218***		
		(0,131)	(0,076)		
Unincorporated technology	Probability	0.028*	0.025***	0.861***	118.0***
		(0,016)	(0,009)		
	Intensity	1.123***	0.361***		
		(0,204)	(0,124)		

Source: Own calculation based on EDIT IV and EAM (DANE)
Note: the conditional marginal effects are reported at the sample mean and robust standard deviation in parenthesis. Observations: 7,069 firms
* Significant at 10% ** Significant at 5% *** Significant at 1%.

Concerning to innovation intensity equations, foreign subsidiaries have more intensive expenditures in R&D and in total innovation activities that domestic firms, both exporters and non-exporters. The superior investment in R&D can be explained mainly by extramural activities[5] that are based

[4]Only the marginal effect is comparable to OLS coefficients, for both selection and intensity equations (Hoffmann & Kassouf, 2005).
[5] In domestic firms, extramural R&D investment is 12%; in foreign subsidiaries, this percentage reaches 45%.

on the association with other organizations. Foreign subsidiaries are also more intensive than domestic firms in activities that require intermediate or basic capacities such as the acquisition of incorporated and unincorporated technology. This result suggests that the technological strategies of foreign subsidiaries in Colombia are more related to the need to establish technological facilities than with the generation of new knowledge, i.e. the predominance of knowledge exploiting strategies based on already existing technological competencies in the multinational group.

The neutral effect of being a foreign firm on the probability of undertaking R&D activities and the positive impact on the investment intensity are in line with the results of Romo & Hill (2006) for Mexico. The behavior in total spending on innovation is also consistent with the evidence provided for Masso et al. (2012) for Estonia, Cassoni & Ramada (2010) for Uruguay, and Arbeláez & Parra (2010) and Gallego et al. (2015) for Colombia.

2.4.2 Innovation outputs

The estimation results of knowledge output are detailed in Table II. 6. Estimation of the innovation outputs containing the marginal effects of the main explanatory variables. We include various versions of the KFP to assess whether foreign subsidiaries have an advantage in the innovation outputs and in the use of inputs and knowledge flows. Considering incremental innovation, except for the reduced model (M0), the relationship between incremental innovation and the condition of being a subsidiary is negative and statistically significant.

In contrast, foreign subsidiaries have greater probability of obtaining radical innovations, and patenting (the latter only in M1 and M3) relative to the reference category of local firms. Domestic exporting firms also have a greater probability of making innovations for the international market and patenting than domestic non-exporting firms, but the associated marginal effects are somewhat less than those in the case of subsidiaries. This evidence is consistent with that provided by Arbeláez and Parra (2010), although these authors used an econometric specification and a different indicator to assess the effect of foreign ownership on innovation outputs.

When we include inputs and knowledge flows (different types of cooperation) in the model of radical innovation, the marginal effect and their statistical significant it is not greatly affected in M1 but if in M2 and M3 models. Here marginal affects attributed to foreign firms decreases substantially (the probability of obtaining radical innovations goes from 7.7% to 1.7% in M2 and to 3.0% in M3). The trend is different in the case of the patenting probability, given that the marginal effect of being a foreign firm is higher with the inclusion of spending on R&D and cooperation variables in M1 and M3 models.

It can be argued that the superiority of subsidiaries in obtaining radical innovations is related to the strong export orientation of foreign subsidiaries in Colombia (around 74% of subsidiaries are exporters). The results could also indicate the possible presence of foreign firms with competences creating strategies that generate competitive advantages in international markets through, for example, the adaptation of innovations to sub-regional markets (e.g. Andean countries) already present in the product range of the multinational group (Papanastasslou & Pearce, 1997; Pearce, 1999). The greater probability of subsidiaries to take out patents could be related to the need of protecting already existing innovations in the multinational group (Criscuolo et al, 2010) not only in the national market but also with the possible extension to sub-regional markets, which could be

due to the effect of trade agreements with countries in the region in which there are special agreements for the protection of intellectual property.

Table II. 6. Estimation of the innovation outputs

Variables independientes	Incremental innovation				Radical innovations				Patenting			
	M0 [(a)]	M1[(b)]	M2[(c)]	M3[(d)]	M0 [(a)]	M1[(b)]	M2[(c)]	M3[(d)]	M0 [(a)]	M1[(b)]	M2[(c)]	M3[(d)]
Tipo de empresa												
Foreign subsidiary	-0,018	-0.073***	-0.246***	-0.238***	0.077***	0.062***	0.017*	0.030**	0.014**	0.018**	0,006	0.017*
	(0,023)	(0,023)	(0,017)	(0,018)	(0,016)	(0,015)	(0,009)	(0,014)	(0,007)	(0,008)	(0,005)	(0,010)
Domestic exporting firm	0.033**	-0.045**	-0.290***	-0.451***	0.072***	0.054***	0.018***	-0,006	0.005*	0.008**	0,001	0,001
	(0,014)	(0,019)	(0,027)	(0,022)	(0,008)	(0,009)	(0,007)	(0,007)	(0,003)	(0,004)	(0,003)	(0,004)
Inputs												
R&D		0.175***				0,009				0.006*		
		(0,045)				(0,008)				(0,004)		
Innovation activities			0.630***				0.037***				0.007***	
			(0,071)				(0,007)				(0,003)	
Intramural R&D				-0,020				0.047**				0,002
				(0,141)				(0,022)				(0,009)
Extramural R&D				3.307***				0.092***				0,017
				(0,349)				(0,035)				(0,013)
Incorporated technology				1.449***				0.073***				0.010**
				(0,096)				(0,011)				(0,004)
Unincorporated technology				-1.112***				-0.076***				-0,015
				(0,171)				(0,022)				(0,010)
Knowledge flows												
Gruop		0.061*	-0,003	-0.064**		0.017*	0,011	0,006		0,000	-0,002	-0,001
		(0,033)	(0,035)	(0,032)		(0,009)	(0,007)	(0,007)		(0,003)	(0,002)	(0,002)
Vertical		0.363***	0.204***	0.226***		0.045***	0.024***	0.028***		0,003	0,001	0,002
		(0,019)	(0,026)	(0,024)		(0,008)	(0,007)	(0,007)		(0,003)	(0,003)	(0,003)
Horizontal		0.080*	0,062	0,073		0,001	0,003	0,002		0,002	0,002	0,002
		(-0,048)	(-0,050)	(-0,052)		(-0,008)	(-0,007)	(-0,008)		(-0,003)	(-0,003)	(-0,003)
Universities/R&D centers		0.083***	0,013	-0,019		0.020**	0.014**	0.014**		0,007	0,005	0,006
		(0,030)	(0,033)	(0,032)		(0,008)	(0,007)	(0,007)		(0,005)	(0,004)	(0,004)
Log likelihood	-3864,3	-3531,7	-3212,8	-2967,9	-1129,1	-1056,4	-1023,9	-998,9	-476,5	-471,7	-469,6	-466,3
Wald chi2	802.3***	1076.5***	1054.9***	1077.5***	426.8***	567.6***	655.2***	751.5***	216.8***	207.2***	221.4***	199.0***
Pseudo R2	0,10	0,18	0,25	0,31	0,19	0,24	0,27	0,28	0,17	0,18	0,18	0,19

Source: Own calculation based on EDIT IV and EAM (DANE)

Note: the conditional marginal effects are reported at the sample mean and robust standard deviation in parenthesis. Observations: 7,069 firms
*Significant at 10% ** Significant at 5% *** Significant at 1%
(a) M0: is the estimated reduced model with the variables of the type of firm and the basic control variables.
(b) M1: includes the estimated intensity of investment in R&D as an explanatory variable.
(c) M2: includes the estimated intensity of investment in innovation activities as an explanatory variable.
(d) M3: includes the separately estimated intensity of investment in the four innovation activities as explanatory variables.

2.4.5 Innovation accounting

Following Criscuolo et al. (2010), in this section we seek to distinguish if innovation-output advantage of foreign subsidiaries is accounted for by their greater use of inputs or their ability to access and use local and global knowledge, and how much is left unexplained.

Table II. 7 and Table II.8 show the innovation accounting results for radical innovation and patenting estimations, aspects in which subsidiaries have advantages in all versions of the KPF (see Table II.6). Here, raw foreign subsidiary–domestic differential is calculated using the data of Table II.4, obtained by subtracting the average values of the innovation variables between foreign firms and domestic non-exporting firms expressed as a percentage (e.g. for radical innovation: 13.9-1.6=12.3%).

Using the data of Table II.6, the adjusted differential for innovation outputs is the marginal effect estimated for foreign subsidiaries in KFP versions, also expressed in percentage. For example, in the case of radical innovation the adjusted differential is the marginal effect of the "subsidiary" variable in M0, in column 5 of Table II.6 (that is, 7.7%). The next rows in Tables II.7 and II.8,

represents the share of the adjusted differential that is explained by the differential use of innovation inputs and knowledge flows between foreign firms and domestic non-exporting firms. For radical innovation, the part of the adjusted differential that is explained by R&D investment is 1.7%.

Finally, the unexplained differential fraction reports the shared of adjusted differential that is unexplained by the estimated regressors, that is, the *per se* effect of being a foreign firm[6]. Taking into account radical innovation, this value is obtained dividing the marginal effect of foreign subsidiaries in M1 over the adjusted differential obtained in the reduced model (M0) (80.5=(6.2/7.7). This surplus margin can be attributed to the characteristic of being a foreign subsidiary.

Table II. 7. Innovation Accounting-R&D (in %). Subsidiaries versus domestic non-exporting firms (Models 1 and 2)

Item	M1		M2	
	Radical innovation	Patenting	Radical innovation	Patenting
Raw foreign subsidiary–domestic differential (observed)	12.3	3.6	12.3	3.6
Adjusted foreign subsidiary–domestic differential (Estimated)	7.7	1.4	7.7	1.4
Fraction of adjusted differential accounted for by:				
Inputs				
R&D intensity	0.01	0.03		
Innovation activities intensity			0.038	0.04
Knowledge flows				
Gruop	2.94	0.03	1,38	-1,9
Vertical	8.47	0.10	4,52	1,04
Horizontal	-0.02	3.11	-0,07	-0,26
Universities/R&D centers	2.16	-0.26	1,51	2,96
Unexplained differential fraction	**80.5**	**128.6**	**22.1**	**42.9**

Source: Own calculation based on EDIT IV and EAM (DANE)

In relation to the results in Table II.7, it should be noted firstly that the superiority of foreign firms in radical innovation is explained more by a greater use of external knowledge flows than by efforts made at R&D; especially, the cooperation with other organizations in the value chain, multinational group and universities and R&D centers. Considering patenting estimation, R&D activities are much more important, while the knowledge acquired externally has a negligible effect. The high value of the unexplained differential (between 75% and 80%, for radical innovation and patenting respectively) implies that much of the difference in knowledge production is explained by the fact of being a foreign subsidiary.

The results shown in Table II. 8 provide additional information considering a broad range of technological activities. We observe that other innovation inputs are much more important that R&D, such as incorporated and unincorporated technology. In addition, it is observed that the unexplained differential fraction is much lower (36%), which indicates that the model seems to adjust better to the process to obtaining radical innovations (in the case of patenting is similar). In particular, it suggests that the superiority of foreign subsidiaries in innovation production is the result of the combined use of internal inputs of greater scale, like R&D, and others that require intermediate or basic capacities, like the acquisition of incorporated technology. In term of

[6]For more details on the calculation see Criscuolo et al. (2010).

knowledge flows, is important the vertical cooperation (clients and suppliers) and with Universities/R&D centers.

Table II. 8. Innovation Accounting- (%) (M3). Subsidiaries versus domestic non-exporting firms (Model 3)

Item	M3	
	Radical innovation	Patenting
Raw foreign subsidiary–domestic differential	12,3	3,6
Adjusted foreign subsidiary–domestic differential	7,7	1,4
Fraction of adjusted differential accounted for by:		
Inputs		
Intramural R&D	7,7	13,6
Extramural R&D	14	18,4
Incorporated technology	60,5	31,9
Unincorporated technology	-97,4	35,2
Knowledge flows		
Gruop	1	-1
Vertical	5,3	2,1
Horizontal	-0,05	-0,3
Universities/R&D centers	1,5	3
Unexplained differential fraction	**36,4**	**85,7**

Source: Own calculation based on EDIT IV and EAM (DANE)

2.5 Conclusions

The possibility of knowledge flows from foreign subsidiaries to the host economies depends on their innovation capacities. This aspect justifies the interest of this contribution, which analyzes the innovation performance of foreign subsidiaries in Colombian manufacturing sector, compared to their domestic counterparts and the explanatory factors of these divergences.

Our main findings are as follows. First, foreign subsidiaries reveal a similar probability to undertake R&D and innovation activities compared to domestic firms, especially those that export. Concerning to innovation effort, foreign subsidiaries show a greater intensity in R&D and innovation activities than exporting and non-exporting domestic firms. However, the major efforts of foreign firms are in extramural R&D activities (carried out by public or private organizations) and other innovation lower-order activities like the investment in incorporated (e.g. machinery and equipment) and unincorporated technology.

Second, the estimation of the knowledge production function shows that foreign subsidiaries have a lower innovation performance than domestic firms in the case of incremental innovations. However, subsidiaries show a greater probability of obtaining radical innovations (toward the international market) and to patent inventions. The importance of radical innovation in foreign subsidiaries can be related with their strong export orientation and the connection of the Colombian economy with sub-regional markets through exports.

Third, the *innovation accounting* exercise explains the sources of differences in innovation performance, and it confirms that foreign firms use comparatively greater internal and external knowledge inputs to produce radical innovations and patenting. At the internal level, activities that

require intermediate or basic technological capacities predominate, while at the external level are important knowledge flows with the multinational groups and with organizations of the national innovation system (clients and suppliers, and, to a lesser degree, universities and research centers).

One result to highlight is that in contrast to prior evidence about the relationship between internationalization and innovation in more developed countries (Castellani & Zanfei, 2007; Criscuolo et al., 2010; Wagner, Joachim, 2006), subsidiaries of multinational firms in Colombia have a similar innovation performance that national firms connected to international markets. The evidence suggests that the foreign subsidiaries in Colombia seem to have distinct mandates, combining strategies of the creation and exploitation of competencies, the latter being the more dominant. That is, multinationals decide to locate R&D and innovation activities to exploit their competitive advantages in the Colombian or sub-regional market more than to create new technological capacities for the group. However, to affirm this more conclusively in-depth study is required in future research.

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Appendix 2.1 Variables definition and statistical descriptives

Independent variables

Indicator	Definition
R&D (Probability)	Dummy equal to 1 if the firm has made investments in R&D and equal to 0 otherwise.
Intramural R&D (Probability)	Dummy equal to 1 if the firm has made investments in intramural R&D and equal to 0 otherwise.
Extramural R&D (Probability)	Dummy equal to 1 if the firm has made investments in extramural R&D and equal to 0 otherwise.
Incorporated technology (Probability)	Dummy equal to 1 if the firm has made investments in incorporated technology and equal to 0 otherwise.
Unincorporated technology (Probability)	Dummy equal to 1 if the firm has made investments in unincorporated technology and equal to 0 otherwise.
Innovation activities investment (Probability)	Dummy equal to 1 if the firm has made investments in innovation activities and equal to 0 in otherwise.
R&D (Intensity)	R&D investment per employee (in logs)
Intramural R&D (Intensity)	Intramural R&D investment per employee (in logs)
Extramural R&D (Intensity)	Extramural R&D investment per employee (in logs)
Incorporated technology (Intensity)	Incorporated technology investment per employee (in logs)
Unincorporated technology (Intensity)	Unincorporated technology investment per employee (in logs)
Innovation activities investment (Intensity)	Total Innovation activities investment per employee (in logs)
Incremental innovation	Dummy equal to 1 if the firm has obtained goods or services new or significantly improved to itself or to the national market and equal to 0 otherwise.
Radical innovation	Dummy equal to 1 if the firm has obtained goods or services new or significantly improved to itself or to the international market and equal to 0 otherwise.
Patenting	Dummy equal to 1 if the firm has applied for or obtained patents of invention and equal to 0 otherwise.

Explanatory variables

Indicator	Definition
Foreign subsidiary	Dummy equal to 1 if the firm has a foreign capital greater than 25% and equal to 0 otherwise
Domestic exporting firm	Dummy equal to 1 if the firm has exported and equal to 0 otherwise
Domestic non-exporting firm (reference)	Dummy equal to 1 if the firm has not exported and equal to 0 otherwise
Size	Large: Dummy equal to 1 if the firm has more than 200 employees and equal to 0 otherwise
	Medium: Dummy equal to 1 if the firm has between 50 and 200 employees and equal to 0 otherwise
	Small: Dummy equal to 1 if the firm has fewer than 50 employees and equal to 0 otherwise
Demand pull	Environmental and safety aspects: Dummy equal to 1 if the firm respond, with a high importance degree, that innovation has an impact on dumping reduction or toxic emissions, as well as improvement in the industrial safety conditions. Equal to 0 otherwise.
	-Regulation and standards: Dummy equal to 1 if the firm respond, with a high importance degree, that innovation has an impact on the fulfillment of regulations, standards and technical regulations. Equal to 0 otherwise.
Innovation cooperation	Dummy equal to 1 if the firm cooperated with other actors in innovation activities and equal to 0 otherwise.
Knowledge flows: Group	Dummy equal to 1 if the firm cooperated with their corporate group in innovation activities and equal to 0 otherwise.
Knowledge flows: Vertical	Dummy equal to 1 if the firm cooperated with clients and suppliers in innovation activities and equal to 0 otherwise.
Knowledge flows: Horizontal	Dummy equal to 1 if the firm cooperated with competitors in innovation activities and equal to 0 otherwise.
Knowledge flows: Universities/R&D centers	Dummy equal to 1 if the firm cooperated with Universities or R&D centers in innovation activities and equal to 0 otherwise.
Public support	Dummy equal to 1 if the firm receives public support to develop innovation activities and equal to 0 otherwise.
Innovation protection	Dummy equal to 1 if the firm protects their innovations through patents, utility models, copyright, industrial designs, distinctive signs and marks. Equal to 0 otherwise.
Sector	R&D intensive sector: CIIU 15,16, 26, 27, 34 y 35
	Scale intensive sector: CIIU 17, 18, 19, 20, 21, 22 y 25
	Specialized suppliers sector: CIIU 23, 24, 31 y32
	Dominated by supplier's sector: CIIU 28, 29 y 33
Information sources: Group	Dummy equal to 1 if the firm uses as innovation sources of information their parent company or other related companies. Equal to 0 otherwise.
Information sources: Vertical	Dummy equal to 1 if the firm uses as innovation sources of information clients and suppliers. Equal to 0 otherwise.
Information sources: Horizontal	Dummy equal to 1 if the firm uses as innovation sources of information their competitors. Equal to 0 otherwise.
Information sources: Universities/R&D centers	Dummy equal to 1 if the firm uses as innovation sources of information universities and R&D centers. Equal to 0 otherwise.

Appendix 2.2 Pairwise correlations

	Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Foreign subsidiary	1.00															
2	Domestic exporting firm	-0.39	1.00														
3	R&D intensity (Log)	0.05	0.23	1.00													
4	Innovation activities intensity (Log)	0.18	-0.03	0.35	1.00												
5	Intramural R&D intensity (Log)	0.08	0.26	0.97	0.34	1.00											
6	Extramural R&D intensity (Log)	0.03	0.06	0.74	0.25	0.60	1.00										
7	Incorporated technology intensity (Log)	0.19	0.04	0.39	0.65	0.36	0.27	1.00									
8	Unincorporated technology intensity (Log)	0.05	0.08	0.58	0.37	0.54	0.56	0.33	1.00								
9	Information sources: Gruop	0.13	-0.03	0.08	0.06	0.09	0.00	0.02	-0.03	1.00							
10	Information sources: Vertical	0.31	-0.10	0.16	0.35	0.18	0.00	0.25	0.18	0.09	1.00						
11	Information sources: Horizontal	0.15	0.07	-0.04	-0.08	-0.01	-0.07	-0.02	0.05	0.13	0.00	1.00					
12	Information sources: Universities/R&D centers	0.10	-0.02	-0.10	0.01	-0.12	-0.12	0.03	-0.07	0.32	0.06	0.36	1.00				
13	Knowledge flows: Gruop	0.05	0.17	0.33	0.23	0.28	0.24	0.19	0.34	0.11	0.44	0.00	0.04	1.00			
14	Knowledge flows: Vertical	0.05	0.08	0.02	0.05	-0.02	0.01	0.07	0.08	0.21	0.13	0.09	0.28	0.38	1.00		
15	Knowledge flows: Horizontal	0.19	0.13	0.03	0.14	0.08	-0.04	0.02	0.12	0.06	0.08	0.40	0.11	0.34	0.29	1.00	
16	Knowledge flows: Universities/R&D centers	0.06	0.25	0.25	0.04	0.28	0.03	0.03	0.10	0.14	0.12	0.18	0.09	0.25	0.34	0.30	1.00

Source: Own calculation based on EDIT IV and EAM (DANE)

Appendix 2.3 Estimation innovation input equations (Expanded)

Independent variables /Dependent variables	(1) R&D		(2) Intramural R&D		(3) Extramural R&D		(4) Innovation activities		(5) Incorporated technology		(6) Unincorporated technology	
	Prob.	**Int.**	**Prob.**	**Int.**	**Prob.**	**Int.**	**Prob.**	**Int.**	**Prob.**	**Int.**	**Prob.**	**Int.**
Foreign subsidiary	0,021	0.535**	0,026*	0,337	0,002	0.917*	0,027	0.626***	0,024	0.508***	0,028*	1.123***
	(0,014)	(0,235)	(0,014)	(0,240)	(0,006)	(0,493)	(0,027)	(0,119)	(0,026)	(0,131)	(0,016)	(0,204)
Domestic exporting firm	0,040***	0.370***	0,040***	0.382***	0,004	0.453*	0,066***	0.309***	0,064***	0.218***	0,025***	0.361***
	(0,009)	(0,139)	(0,009)	(0,146)	(0,004)	(0,270)	(0,016)	(0,068)	(0,015)	(0,076)	(0,009)	(0,124)
Public support	0,211***	0,341	0,168***	0,369	0,095***	0,187	0,614***	0.499***	0,523***	0.471**	0,176***	0,39
	(0,054)	(0,308)	(0,050)	(0,329)	(0,033)	(0,356)	(0,006)	(0,174)	(0,048)	(0,196)	(0,050)	(0,244)
Innovation protection	0,120***	-0,031	0,108***	0,019	0,034***	-0,001	0,304***	0,073	0,270***	-0,027	0,142***	0,032
	(0,013)	(0,139)	(0,012)	(0,147)	(0,007)	(0,279)	(0,017)	(0,068)	(0,017)	(0,073)	(0,013)	(0,118)
Innovation cooperation		0,128		0,159		-0,053		0.290***		0.181**		0.223*
		(0,146)		(0,152)		(0,309)		(0,067)		(0,072)		(0,124)
Sector												
R&D intensive	0,080***	0.697***	0,079***	0.759***	0,011*	0,37	0,072***	0.261***	0,040**	-0,064	0,094***	0.841***
	(0,014)	(0,170)	(0,014)	(0,176)	(0,006)	(0,414)	(0,021)	(0,090)	(0,020)	(0,098)	(0,016)	(0,159)
Escale intensive	0,011	0,121	0,010	0,048	0,005	0,354	0,033**	0.129*	0,030**	0,068	0,048***	0,2
	(0,009)	(0,162)	(0,008)	(0,168)	(0,004)	(0,316)	(0,015)	(0,074)	(0,015)	(0,080)	(0,010)	(0,134)
Specialized suppliers	0,024**	0,1	0,024**	0,046	-0,000	0.733**	0,025	0,077	0,017	0,013	0,034***	0.314*
	(0,012)	(0,198)	(0,011)	(0,208)	(0,005)	(0,367)	(0,019)	(0,084)	(0,019)	(0,092)	(0,013)	(0,170)
Demand pull												
Environmental and safety aspects		-0,121		-0,08		-0,676		0.425***		0.440***		0,26
		(0,208)		(0,228)		(0,637)		(0,096)		(0,101)		(0,205)
Regulation and standards		0,066		0,001		0,423		0,113		0,076		-0,067
		(0,221)		(0,239)		(0,642)		(0,096)		(0,101)		(0,206)
Information sources												
Internal		0,329		0,335		0,465		0.167**		0,048		0,014
		(0,285)		(0,281)		(0,659)		(0,083)		(0,088)		(0,185)
Group		0.452**		0.446**		-0,084		0.374***		0.452***		0.269*
		(0,203)		(0,208)		(0,366)		(0,111)		(0,120)		(0,163)
Vertical		-0,022		-0,105		-0,111		0,098		-0,019		-0,035
		(0,163)		(0,175)		(0,353)		(0,071)		(0,075)		(0,138)
Horizontal		-0,095		-0,124		-0,081		0,064		-0,002		-0,092
		(0,144)		(0,154)		(0,245)		(0,070)		(0,077)		(0,123)
Universities/R&D centers		-0,007		-0,063		0,179		0,053		-0,017		0,028
		(0,156)		(0,162)		(0,293)		(0,086)		(0,094)		(0,132)
Size												
Large	0,172***		0,151***		0,057***		0,348***		0,341***		0,192***	
	(0,018)		(0,018)		(0,010)		(0,020)		(0,022)		(0,019)	
Medium	0,050***		0,045***		0,014***		0,199***		0,194***		0,076***	
	(0,009)		(0,009)		(0,004)		(0,015)		(0,015)		(0,010)	
Rho	0.848***		0.859***		1.199***		0.636*		0.740*		0.861***	
Log likelihood	-3594,0		-3369,9		-1185,7		-5379,9		-4938,6		-3900,7	
Wald chi2	78,4***		77,2***		33,7***		222,1***		117,2***		118,0***	
Observations	7.069		7.069		7.069		7.069		7.069		7.069	
Censored observations	6.314		6.376		6.873		4.275		4.523		6.211	
Uncensored observations	755		693		196		2.794		2.546		858	

Source: Own calculation based on EDIT IV and EAM (DANE)

Appendix 2.4 Estimation of the innovation outputs (Expanded)

Independent variables /Dependent variables	Incremental innovation				Radical innovation				Patenting			
	M0 [a]	M1[b]	M2[c]	M3[d]	M0 [a]	M1[b]	M2[c]	M3[d]	M0 [a]	M1[b]	M2[c]	M3[d]
Type of firm												
Foreign subsidiary	-0,018	-0.073***	-0.246***	-0.238***	0.077***	0.062***	0.017*	0.030**	0.014**	0.018**	0,006	0.017*
	(0,023)	(0,023)	(0,017)	(0,018)	(0,016)	(0,015)	(0,009)	(0,014)	(0,007)	(0,008)	(0,005)	(0,010)
Domestic exporting firm	0.033**	-0.045**	-0.290***	-0.451***	0.072***	0.054***	0.018***	-0,006	0.005*	0.008**	0,001	0,001
	(0,014)	(0,019)	(0,027)	(0,022)	(0,008)	(0,009)	(0,007)	(0,007)	(0,003)	(0,004)	(0,003)	(0,004)
Inputs												
I+D intensity (Predicted)		0.175***				0,009				-0.006*		
		(0,045)				(0,008)				(0,004)		
Innovation activities intensity (Predicted)			0.630***				0.037***				0.007***	
			(0,071)				(0,007)				(0,003)	
Incorporated technology intensity (Predicted)				1.449***				0.073***				0.010**
				(0,096)				(0,011)				(0,004)
Unincorporated technology intensity (Predicted)				-1.112***				-0.076***				-0,015
				(0,171)				(0,022)				(0,010)
Knowledge flows												
Gruop		0.061*	-0,003	-0.064**		0.017*	0,011	0,006		0,000	-0,002	-0,001
		(0,033)	(0,035)	(0,032)		(0,009)	(0,007)	(0,007)		(0,003)	(0,002)	(0,002)
Vertical		0.363***	0.204***	0.226***		0.045***	0.024***	0.028***		0,003	0,001	0,002
		(0,019)	(0,026)	(0,024)		(0,008)	(0,007)	(0,007)		(0,003)	(0,003)	(0,003)
Horizontal		0.080*	0,062	0,073		-0,001	-0,003	-0,002		-0,002	-0,002	-0,002
		(0,048)	(0,050)	(0,052)		(0,008)	(0,007)	(0,008)		(0,003)	(0,003)	(0,003)
Universities/R&D centers		0.083***	0,013	-0,019		0.020**	0.014**	0.014**		0,007	0,005	0,006
		(0,030)	(0,033)	(0,032)		(0,008)	(0,007)	(0,007)		(0,005)	(0,004)	(0,004)
Size												
Large	0.323***	0.080*	-0.423***	-0.619***	0.051***	0,012	-0.030***	-0.043***	0,006	0,017	-0.007***	-0.006*
	(0,022)	(0,048)	(0,024)	(0,026)	(0,010)	(0,013)	(0,004)	(0,006)	(0,004)	(0,013)	(0,002)	(0,004)
Medium	0.156***	0.087***	-0.473***	-0.713***	0.018***	0,008	-0.031***	-0.050***	0,001	0,003	-0.007***	-0.006*
	(0,015)	(0,018)	(0,037)	(0,029)	(0,005)	(0,005)	(0,006)	(0,008)	(0,002)	(0,003)	(0,003)	(0,004)
Sector												
R&D intensive	0.095***	-0,035	-0.235***	0.105**	0.018**	0,002	-0.013***	0,001	0.010**	0.020*	0,002	0,025
	(0,019)	(0,031)	(0,024)	(0,047)	(0,007)	(0,009)	(0,004)	(0,011)	(0,004)	(0,010)	(0,003)	(0,015)
Escale intensive	-0,002	-0,023	-0.171***	-0.174***	-0,003	-0,006	-0.015***	-0,006	0.006**	0.006**	0,003	0,008
	(0,014)	(0,014)	(0,021)	(0,023)	(0,004)	(0,004)	(0,004)	(0,006)	(0,003)	(0,003)	(0,002)	(0,005)
Specialized suppliers	0.044**	-0,002	-0.094***	0.041*	0.016**	0,009	0,000	0,011	-0,002	-0,001	-0,003	0,000
	(0,018)	(0,018)	(0,019)	(0,024)	(0,007)	(0,006)	(0,005)	(0,007)	(0,003)	(0,003)	(0,002)	(0,004)
Other control variables												
Public support	0.342***	-0,061	-0.297***	-0.338***	0.054**	0,001	-0.023***	-0.025***	0,005	0,037	-0.007***	-0.007***
	(0,062)	(0,083)	(0,007)	(0,009)	(0,026)	(0,020)	(0,002)	(0,002)	(0,009)	(0,043)	(0,001)	(0,001)
Innovation protection	0.258***	0,031	-0.485***	-0.669***	0.056***	0,02	-0.032***	-0.044***	0.046***	0.067***	0,004	0,012
	(0,017)	(0,041)	(0,031)	(0,028)	(0,008)	(0,013)	(0,005)	(0,007)	(0,007)	(0,020)	(0,008)	(0,014)
Log likelihood	-3864,3	-3531,7	-3212,8	-3047,2	-1129,1	-1056,4	-1023,9	-1017,7	-476,5	-471,7	-469,6	-468,8
Wald chi2	802.2***	1076.5***	1054.9***	885.8***	426.8***	567.6***	655.2***	698.6***	216.8***	207.1***	221.3***	201.1***
Pseudo R2	0,10	0,18	0,25	0,29	0,19	0,24	0,27	0,27	0,17	0,18	0,18	0,19
Observacions	7069	7069	7069	7069	7069	7069	7069	7069	7069	7069	7069	7069

Source: Own calculation based on EDIT IV and EAM (DANE)

CHAPTER III. EXTERNAL AND INTERNAL NETWORKING AND THE INNOVATION PERFORMANCE OF FOREIGN SUBSIDIARIES

3.1 Introduction

Since the late 1990s, the expansion of competition and decentralization of production have also accelerated the process of knowledge generation over international bases. The consequence has been that the maintenance of firm's competitive advantage depends not only on the evolution of own innovation initiative, but increasingly on the ability to identify, assimilate and integrate different knowledge sources and capabilities (Cohen & Levinthal, 1990; Chesbrough, 2006; Von Hippel, 2005). Multinational enterprises (MNE) have a strategic position to respond to these changing conditions, due to their privileged access to several internal and external knowledge bases dispersed around the world (Birkinshaw et al., 2005; Criscuolo et al., 2010; Figueiredo & Brito, 2011; Phene & Almeida, 2008).

The recognition of the crucial role of inter-organizational networks with internal partners and external organization as a driver of competence development in MNE subsidiaries has been a topic of growing interest in International Business (IB) approach. Scholars have developed models such as the "hypermodern heterarchy" (Hedlund, 1986) and the federative multinational (Ghoshal & Bartlett, 1990) to reflect the critical role played by different MNE subunits to coordinate diversified and geographically disperse value-added activities and capabilities, both within the organization and with external actors in different economic and institutional environment settings (Meyer, 2011). A wide range of IB contributions has encountered evidence about individual subsidiaries that are augmenting their innovation and creative activities, even in less developed economies, through which the generation and diffusion of innovations within the multinational network has been expanded (Cantwell & Mudambi, 2005; Iammarino & McCann, 2013; Marin & Arza, 2010; Mudambi, 2008; UNCTAD, 2005).

A key understanding aspect of how subsidiaries acquire or evolve towards more creative responsibilities is the way that these units can develop skills to tap into and to absorb different knowledge sources from multiple contexts. In fact, the evidence has revealed that, together with their initiative or business attitude, a crucial determinant of the development of distinctive competences in foreign subsidiaries is the combination of resources and capabilities achieved via linkages with other organizations in the host country -such as customers, suppliers, and local universities- and with members of their internal MNE networks – i.e. headquarter and other subsidiaries (Achcaoucaou et al., 2014; Andersson & Holm, 2002; Figueiredo, 2011; Golebiowski, 2015; Phene & Almeida, 2008; Yamin & Andersson, 2011). This ability to connect and integrate simultaneously MNE internal and

external capabilities, across heterogeneous contexts, has been referred in the literature as dual-embeddedness and is recognized as one of the main drivers of the generation of unique and sustainable competitive advantages in multinational firms (Forsgren, 2005; Meyer, 2011).

Despite the increasing attention in the IB literature in assessing the effects of the subsidiary´s dual-embeddedness on their innovation scope and initiative, there is still limited evidence for foreign subsidiaries located in developing countries in comparison to that available for developed ones. This is an important aspect considering that the degree of development of the national systems of innovation (NSI) may have significant effects on the competitive and innovation strategies followed by foreign subsidiaries and the characteristics of technology sourcing process (Birkinshaw et al., 2005; Carlsson, 2006; Figueiredo, 2011).

Another limitation of previous literature has been that most of the analysis usually looks separately the impact of external or internal network on innovation performance; paying less attention to the possible interdependences or trade-off between both types of networks (Ciabuschi et al., 2014; Yamin & Andersson, 2011). Although dissemination of externally acquired knowledge inside the MNE requires at the same time high internal embeddedness (Bresciani & Ferraris, 2016), it is not always possible to anticipate a positive interaction between the two types of networks because resources are limited within an organization and the degree of local responsibility is undergone to the integration into the MNE network and vice versa (Andersson, 2003; Gammelgaard et al., 2012; Wang, 2009; Yamin & Andersson, 2011).

In this article, we explore the effects of technical external and intra-corporate networks on innovation performance of foreign subsidiaries in the Colombian manufacturing sector, as well as the possible interdependences among these knowledge sources to explain subsidiary´s technological capacities. We formulated a structural model to estimate our set of hypothesis, using a biennial panel (2008-2012) of manufacturing Colombian firms. Complementarily, in this study we assess the role of knowledge absorptive capacity (Cohen & Levinthal, 1990), explaining it as a determinant factor for the establishment of both external and internal networking in foreign subsidiaries, and their impacts. This issue is relevant because subsidiary's engagement in external and internal networks may be conditioned by its previously accumulated capabilities, as well as their innovation performance. To fulfill this purpose, we estimate a model of the determinants of the probability that foreign subsidiaries are connected to internal and external knowledge sources.

The remainder of this paper is structured as follows. The next section overviews the theoretical framework of the study and the formulation of hypothesis. In the third section, we illustrate the methodology, in particular, the data used and the empirical methods. In section fourth, we discuss the findings of the empirical exercise. Finally, in the fifth section, we provide conclusions as well as some key implications.

3.2 Theoretical framework and hypothesis

3.2.1 Network embeddedness as a strategic resource

According to network theory, economic exchanges are 'embedded' in social and cultural environments and this process plays a significant role in the competitive performance of organizations (Granovetter, 1985; Gulati et al., 2000; Powell & Giannella, 2010; Uzzi, 1996). Essentially, this approach emphasizes in some emerging properties of network ties that permit the access of organizations to strategic assets and resources in order to improve their competitive advantage (Dacin, 1999; Garcia-Pont, 2009).

The notion of embeddedness is then seen as a strategic resource. There are several dimensions of it: Structural, relational and technical. The structural dimension refers to the particularities of network architecture and the advantages that an organization can derive from their position in an inter-organizational network; whereas, relational embeddedness stresses the role of quality ties and exchanges of distinctives resources and competences between organizations (Dacin, 1999; Granovetter, 1985; Gulati et al., 2000). In this paper, we concentrate on the relational dimension of embeddedness.

The relational embeddedness can be of various types, which represent different opportunities for learning; this can range from arm's-length linkages to knowledge-intensive linkages (Andersson, 2003; Dacin, 1999; Figueiredo, P. N., 2011; Uzzi, 1996). Arm's length linkages are based on a lack of social closeness between actors, market transactions, impersonal links and profit-seeking logic (Andersson, U., 2003; Uzzi & Lancaster, 2003). In contrast, knowledge-intensive linkages are characterized by a high degree of mutual and long-term adaptation, cooperation, trust and reciprocity (Forsgren, 2005; Uzzi, 1996). The embedded relationships are focused on the exchange of knowledge of increasingly cognitive complexity, e.g. training, product and process development and R&D (Ciabuschi et al., 2014; Figueiredo, 2011) and have individual and collective benefits in terms of high learning capabilities, risk reduction, invest sharing and greater innovation speed (Hagedoorn et al., 2000; Uzzi, 1996; Uzzi & Lancaster, 2003). In most cases, relationships are between these two extremes. However, there is a higher degree of embeddedness when the ties move away from the arm's-length relationships (Uzzi, 1997).

Moreover, we concentrate on the technical embeddedness in network relationships, which is defined as the interdependencies and mutual adaptations in developing technological innovations between the subsidiary and local counterparts as well as linkages with other units of the multinational corporation (Andersson, 2003; Andersson & Holm, 2007; Forsgren, 2005; Giroud, 2009). At the external level, we will consider a wide range of subsidiary's partners and not only business counterparts. We contemplate ties ranging from those established in the value chain and competitors, to more knowledge-intensive ties developed with R&D organizations. At the corporate level, we consider the innovation relationships established by the subsidiary with their parent company and other MNE units.

3.2.2 External networks

External networks involve a set of relationships that take place among firms and local organizations such as customers, suppliers, competitors (both indigenous companies and other MNC subsidiaries), universities, research centers and other experts, with which the different units of the MNE interact to develop their business or innovation activities. The external relations of the subsidiaries are mostly local (although not always) within the host country and have a strong local emphasis (Birkinshaw et al., 2005; Frost, 2001; Santangelo, 2009; Yamin & Andersson, 2011).

There is a strong relationship between subsidiary´s external linkages and their strategic orientation, either exploitation (exploit in a foreign country the knowledge previously existing in the MNE) or creation of technological competencies (creation or acquisition of new knowledge and skills in order to increase MNE´s capabilities) (Cantwell & Mudambi, 2005; Giroud, 2009). In other words, subsidiary mandates can evolve according to changes in its degree of external network embeddedness (Achcaoucaou, 2014; Marin & Bell, 2010). Considering that national innovation systems tend to develop distinctive technological specialization and trajectories (Cantwell, 1989), competence-creating subsidiaries can take advantage from access to local specific knowledge and thus to improve their innovation capacities (Phene & Almeida, 2008). In particular, in competence-creating subsidiaries it is relevant to exploit specific location-advantages such as highly skilled human capital, the infrastructure and institutions that support innovation, as well as sectoral and local firm's endowments and capabilities (Collinson, 2012; Dunning, 2009; Florida, 1997; Frost et al., 2002; Giroud, 2009; Meyer, 2011; Narula, 2002; Silva et al., 2013). Some authors have found that the greater the creative responsibilities of subsidiaries are, the better is its ability to establish external networks with host country organizations. This is because they have more autonomy to develop local linkages (Birkinshaw et al., 1998; Nobel & Birkinshaw, 1998; Andersson & Forsgren, 2000; Andersson & Holm, 2007). In contrast, competence-exploiting subsidiaries tend to establish weak linkages with host innovation systems and are more dependent of corporate internal knowledge in their business and innovation activities, due to its lower autonomy and low incentives to connect with local partners (Andersson & Holm, 2007; Golebiowski, 2015; Kokko & Kravtsova, 2008).

The advantages of external networks have special features depending on the type of partners. Business relationships with clients and suppliers are crucial to develop firm´s competences and innovation in products and processes (Tether, 2002; Von Hippel, 1998). These linkages permit the subsidiaries to have a greater ability to assess the needs and requirements of their business counterparts and to have a better understanding of what innovations are acceptable or not in a particular market, reducing the risk of launching new products or the implementation of a new process (Birkinshaw et al., 2005; Bresciani & Ferraris, 2016; Ciabuschi et al., 2014). Ties with competitors can foster the establishment of standards in the introduction of new goods or services or it can serve to share innovation investments with high costs for a single firm (Tether, 2002). Competitors are also a source of reverse

knowledge spillovers toward foreign subsidiaries (Ambos, 2006; Driffield et al., 2014; Yang et al., 2008), e.g. through the imitation of capabilities and technologies (Figueiredo, P. & Brito, 2011). Universities and R&D centers are important contributors to supply scientific and technological knowledge, enabling the access to emerging technologies and specialized technological support (Tether, 2002). Recent studies have pointed out that collaboration between subsidiaries, universities and other R&D organizations is central to technology sourcing strategies within the MNE network (Broström et al., 2009; Guimon, 2015; Santangelo, 2009).

In general, empirical studies have found a positive impact of external linkages on subsidiary's innovation competences. For example, Andersson (2002) found that subsidiary's external networks affect positively their role as a provider of knowledge about product and process development toward other Swedish MNE units. Using USPTO patent data for subsidiaries of the US semiconductor industry, Phene & Almeida (2008) corroborate that host country knowledge is critical to the scale and quality of innovations obtained. Applying a case study for seven subsidiaries located in Brazil, Figueiredo (2011) found that higher levels of innovation performance are associated with continuous linkages with local actors; in particular, with universities and research institutes. According to Golebiowski (2015), there are positive linkages between external networks and product innovation, but this relationship is mediated indirectly by the autonomy of the subsidiary, because increases in autonomy lead to increases in external network linkages. On the bases the of previous argumentation and the available empirical evidence, our first hypothesis is as follows:

H1: Technical linkages with external sources of knowledge are positively related to the innovation performance of foreign subsidiaries.

3.2.3 Internal network

The internal network is composed by all the subsidiary´s relationships with different units within a multinational, i.e. with their parent company or with other sister subsidiaries in third countries. The effect of a greater internal integration of subsidiaries on their innovation performance is diverse. Understanding MNE as a social network makes it an appropriate vehicle for mutual adaptation and integration of globally dispersed knowledge (Birkinshaw & Hood, 1998; Ghoshal & Bartlett, 1990; Kogut & Zander, 1993). In internal networks, each unit of the group learns from the environment in which it operates and transmits that knowledge within the corporation (Frenz & Ietto-Gillies, 2007). The corporate linkages facilitate the communication of needs and opportunities related to innovation that has their origin in different institutional and economic contexts (Ciabuschi et al., 2014; Monteiro, 2008). This permits to MNE to take advantage of the technological specialization of local subsidiaries and organizations (Kogut & Zander, 1993; Phene & Almeida, 2008; Zander, & Sölvell, 2000) and reduce the time and space to innovate based on the subsidiary own technology (Fan-Yi, 2016). Also, the internal networks are more efficient for sharing tacit and complex knowledge by belonging to a common social community characterized by trust

relationship, shared norms and sustained and repeated interactions (Gnyawali et al., 2009; Zander & Kogut, 1995).

However, internal linkages not always provide the same learning and knowledge opportunities. Some factors that can affect the effectiveness of the internal linkages are: (i) weak motivations and incentives for knowledge sharing inside the MNE (Gupta & Govindarajan, 2000; Kogut & Zander, 1993); (ii) the high specificity of shared knowledge due to complex and idiosyncratic interactions with local partners (Achcaoucaou et al., 2014; Andersson & Holm, 2007) and (iii) high coordination and control costs of managing complex and widely distributed spatial activities (Meyer, 2011). Also, the subsidiary´s technological initiative influences knowledge flows and innovation development through internal network. In competence creating subsidiaries there is greater probability to cooperate with other MNE units, as internal network linkages serve as a key channel through which distinctive and valuable knowledge is distributed to the rest of the MNE (Achcaoucaou et al., 2014; Ambos, 2006; Phene & Almeida, 2008). Meanwhile, competence-exploiting subsidiaries can be less motivated to learn from other subsidiaries since they do not have the sufficient knowledge absorptive capability to take advantage of networking opportunities and could have lower motivation to develop their own technology because they lack the urgent need for innovation (Fan-Yi, 2016).

All these factors could explain why the reduced impact of subsidiary´s internal networks on innovation in some cases; the evidence is indeed mixed on the subject. Empirical findings for the United Kingdom show that intra-company knowledge transfers are relevant in explaining subsidiary innovation performance (Frenz, Marion & Ietto-Gillies, 2009). For six large Swedish multinationals, Monteiro et al. (2008) found that subsidiaries do not share knowledge or do not learn from each other—i.e. are isolated subsidiaries— and they perform poorly and are separated from MNE knowledge diffusion activities. Fan–Yi (2016) provide evidence about a negative impact of internal network on innovation investment using worldwide databases of subsidiaries (OSIRIS and WHIPS). Also, Yamin (2011) found that internal embeddedness negatively impacts a subsidiary's importance for product development in Swedish subsidiaries.

Additional evidence of the positive impact of internal ties on innovation performance is provided for Garcia-Pont et al. (2009) for Spain, Figuereido & Brito (2011) for Brazil, Collison et al (2012) for Taiwan and Gammergaard et al (2012) for subsidiaries located in the UK, Germany and Denmark. In contrast, empirical evidence of a neutral effect of internal ties on innovation performance is found by Phene & Almeida (2008) for the USA semiconductor subsidiaries and in a Ciabuschi et al. (2014) study of subsidiaries located in 14 countries.

According to the arguments exposed in this section, we can expect both a positive or negative effect of internal networks on innovation performance. Thus, our second hypothesis is as follows:

H2: Technical linkages with internal sources of knowledge (parent companies and other MNE subunits) are positive (negatively) related to innovation performance of foreign subsidiaries.

3.2.4 Internal and external networks

To focus only on local or internal context may be limited because it does not provide an analytical framework on how multinationals adapt to widely varying local contexts simultaneously (Meyer, 2011) and take advantage of the opportunities that emerge from the interactions between both evolving environments in a path-dependent process (Achcaoucaou, et al., 2014; Birkinshaw et al., 2005; Gulati et al., 2000).

The study of dual embeddedness is a relatively recent topic in IB literature. Two central concerns could be distinguished: First, whether the subsidiary operates in two separate networks or in interrelated networks, i.e. if there are interdependencies or trade-off mechanisms between external and internal networks. Secondly, how the interaction between internal and external linkages affects the productive and technological performance of subsidiaries as well as their competences evolution.

We identify here two principal aspects that could explain interdependencies and complementarities between the two networks considered. First, although subsidiaries need to be well embedded within local context in order to acquire greater innovation capacities; however, the dissemination and the use of this knowledge inside the MNE may require sufficient MNE internal embeddedness (Achcaoucaou, F. et al., 2014; Andersson, 2003; Ciabuschi et al., 2014; Gammelgaard et al., 2012). In fact, the ability to create, transfer, recombine, and exploit resources across multiple contexts is at the core of the explanation of the existence of MNE (Meyer, 2011). Second, there is a strong relationship between the level of subsidiary´s initiative and the process of technology sourcing and knowledge flows within MNE. Most strategically autonomous subsidiaries have a greater ability to create a dependence of their resources by other units of MNE, which is achieved through high levels of external embeddedness as this provides them attractive and unique competences to all multinational corporation (Achcaoucaou et al., 2014; Birkinshaw & Hood, 1998; Gammelgaard et al., 2012). The result could be that the larger the interdependence in these relationships, the better the position of the subsidiary within MNE network and the more pronounced will be their innovative activities (Andersson & Holm, 2002; Boehe, 2007; Ciabuschi et al., 2014; Garcia-Pont, 2009).

On the other hand, external and internal network can be in conflict with each other for several reasons. First, alike any other organization, MNE have limited resources, which mean that greater local responsibility of the subsidiaries can come at the expense of a lower internal integration and vice versa (Forsgren, 2005; Gammelgaard et al., 2012). Second, there is a competitive mechanism inside MNE for the distribution of responsibilities. In this context, the strong competition for resources among subsidiaries may limit the interest in sharing knowledge within the corporation (Meyer, 2011). Third, greater integration and dependence

of subsidiaries to their MNE network can involve the risk of reducing necessary autonomy to develop their own innovation capacities (Andersson, U. F., M. Holm, U., 2007) and decrease the incentives to use external knowledge (Gammelgaard et al., 2012). Fourth, the context specificity of the knowledge generated at the subsidiary level in interaction with local partners, can be an obstacle to knowledge flows toward other corporate units (Achcaoucaou et al., 2014; Andersson & Holm, 2002, 2007; Boehe, 2007).

The effect of dual embeddedness on subsidiary´s innovative capacity depends on the result of interaction between their external and internal networks, i.e. if there are complementarities or a trade-off between them. In Sweden, Yamin et al (2011) found a negative interaction effect between internal and internal networks on a subsidiary's importance for product development. However, most empirical studies seem to indicate that the positive effects of dual networks are strong enough to compensate the eventual negative impact of interactions between internal and external linkages. For Argentina, Marin & Bell (2010) obtained that well-integrated subsidiaries within both the local economy and their parent firm globally are more innovative. Figueiredo & Brito (2011) found that the most innovative foreign subsidiaries in Brazil are those connected to both external and internal partners and also exploit their complementarities as a source of strategic competencies.

Accordingly, we can expect that those subsidiaries that develop internal or external linkages have better innovation performance. Meanwhile, although we predict a relationship between internal and external networks, there is not necessarily a predicted sign. This leads us to the following hypotheses:

H3: Simultaneous technical linkages with external and internal sources of knowledge are positively related to innovation performance of foreign subsidiaries.

H4: Technical linkages with external sources of knowledge are related positively/negatively with internal networks.

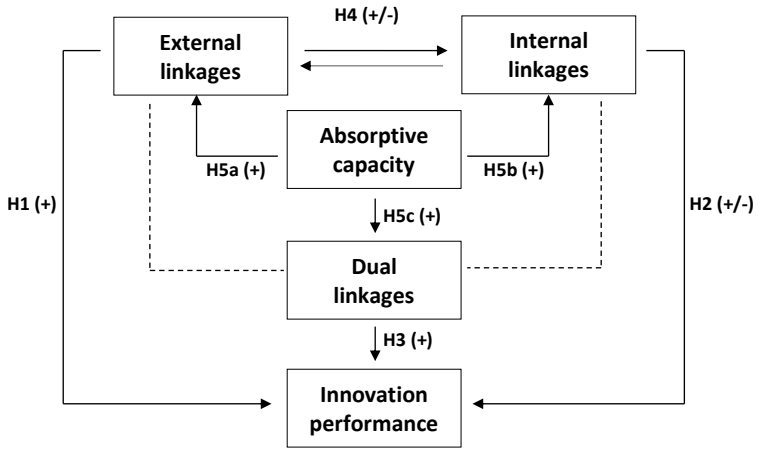
3.2.5 The role of absorptive capacity

The capability of subsidiaries to exploit external and corporate opportunities and resources, is linked closely to its absorptive capacity (Birkinshaw & Hood, 1998; Gupta & Govindarajan, 2000), understood as the ability to ‘‘recognize the value of new, external knowledge, assimilate it, and apply it to commercial ends" (Cohen & Levinthal, 1990, p. 128). Monteiro (2008) found greater knowledge outflows occurring from subsidiaries that are perceived to be highly capable by other subsidiaries in MNE network, because those units are more motivated to search external and corporate knowledge. Similar result was provided by Boehe (2007) since high internal interdependence between subsidiaries and their MNE network is related to a strong in-house research and innovation development activities. Besides, Figuereido & Brito (2011) provide evidence that those subsidiaries that develop more linkages with local organizations for sophisticated activities are those that have accumulated greater innovation capabilities. In line with this view, we propose the following hypothesis:

H5: A greater absorptive capacity of foreign subsidiaries affects positively the probability to be engaged in internal and external networks.

Overall, our hypotheses are summarized in Figure III. 1, which we confront using empirical data.

Figure III. 1. The hypothesized model



3.3 Methodology

3.3.1 Data

The data set used in the empirical analysis comes from a survey of innovation in Colombia, called the Development and Technological Innovation Industrial Survey (EDIT, for its acronym in Spanish), for the period 2007-2012, gathered by Colombia's national statistics department (Dane)[7]. This survey collects two-year information about innovation activities undertaken by industrial firms. We focus on three of the most recent waves of the survey, which are those that show a better data quality and comparability of the questionnaires: EDIT IV (2007-2008), EDIT V (2009-2010) and EDIT VI (2011-2012).

After a process of cleaning the database to correct inconsistencies and missing values, we obtained an unbalanced panel with 23,952 observations. For purposes of the study, we built a database specifically for foreign subsidiaries, which is composed of 411 firms and 1,150 observations. Foreign subsidiaries are defined as those having a proportion of foreign capital equal or greater than 25 percent. Table III. 1 shows the main characteristics of the database.

[7] The firm-level data provided by this statistic agency are subject to strict regulation of the statistical reserve. Hence, the data were worked directly at DANE's offices through the signing of a specific agreement of collaboration.

Table III. 1. Characteristics of the sample of foreign subsidiaries

Observations	1,150
Firms	411
Consecutive observations by firm (average)	2.8
Foreign capital (2012)	Between 25 and 50 percent: 23.6% Greater than 50 percent: 74.6%
Size (2012)	Small: 13.5% Medium: 39.6% Large: 46.8%
Sector by technological intensity (2012)	R&D intensive sector: 6.1% Scale intensive sector: 30.7% Labor intensive sector: 26.0% Natural resources intensive sector: 37.1%

Source: Own calculation based on DANE - EDIT and EAM

3.3.2 Model specification

To test hypotheses H1, H2 and H3, defined in section 2, we used regressions in which innovation performance is explained by different sources of knowledge (internal, external and dual networks) plus a set of control variables. Particularly, we used an extended CDM framework (Crépon et al., 1998) to estimate innovation inputs, innovation outputs and knowledge production function, as measures of innovation performance in subsidiaries. The model takes the following form:

$$y_{0it} = \begin{cases} 1 \text{ if } y^*_{0it} = \psi_0 NET_{it,k} + \beta_0 X_{0it} + \mu_{0i} + \varepsilon_{0it} > 0 \\ 0 \text{ if } y^*_{0it} = \psi_0 NET_{it,k} + \beta_0 X_{0it} + \mu_{0i} + \varepsilon_{0it} \leq 0 \end{cases} \quad (Eq.\ 1)$$

$$y_{1it} = \begin{cases} y^*_{1it} = \psi_1 NET_{it,k} + \beta_1 X_{1it} + \mu_{1i} + \varepsilon_{1it} & \text{if } y_{0it} = 1 \\ 0 & \text{if } y_{0it} = 0 \end{cases} \quad (Eq.\ 2)$$

$$y_{2it} = \alpha \hat{y}_{1it} + \psi_2 NET_{it,k} + \beta_2 X_{2it} + \mu_{2i} + \varepsilon_{2it} \quad (Eq.\ 3)$$

Where subscripts i and t refer to firm and year, respectively. In equation 1, y^*_{0it} is a latent decision variable measuring the propensity to innovate and, associated with this, y_{0i} is a binary variable which is equal to 1 if the firms invest in R&D, and 0 otherwise. In equation 2, the variable y_{1it} is the intensity of investment in R&D activities (in logs). The equation 3 is the knowledge production function, where y_{2it} is knowledge proxied by both the product and process innovation indicators.

In the structural model, $NET_{it,k}$ is a vector of networking indicators related to external, internal or dual linkages (for k = 1, 2 and 3 types of networks) and X_{0it}, X_{1it} and X_{2it} are the vector of firm specific control variables: Size, export, age, share of foreign capital and a set of dummy variables for labor, natural resource, R&D and scale intensive sectors. In equation 3, $\hat{y}_{1it}$ is the predicted innovation intensity estimated in previous staged. The ψ_s , β_s and α are the unknown parameter vectors. The permanent unobserved firm heterogeneity is captured by μ_{0i}, $\mu_{1i}$and μ_{1i}. Finally, ε_{0it}, ε_{1it} and ε_{3it} are error terms of the equations.

In order to test our hypothesis H4 and H5 (a, b and c), we estimated a model of the likelihood that subsidiaries establish internal, external and dual linkages. The general structure of the probit model is as follows:

$$\Pr[NET_{it,k} = 1] = \Phi(\beta_k Z_{it} + \mu_{i,k} + \omega_{it,k}) \quad (Eq.\ 4)$$

Where Pr is the probability and Φ is the probit function – the standard cumulative normal distribution. Here, $NET_{it,k}$ are dummies variables indicating if firm i establish external, internal or dual knowledge linkages at time t, Z_{it} is the vector of explanatory variables, β_k, is the vector of unknown coefficients, $\gamma_i$is the unobserved heterogeneity and ω_{it} is the error term. To evaluate if technical linkages with external sources of knowledge are related positively o negatively with internal networks (hypothesis H4), we included in Z_{it} an external network indicator when the dependent variable is an internal network dummy and vice versa. To test the H5 (a, b and c) we also include in the vector of explanatory variables a firm´s absorptive capacity indicator as a determinant of the probability that subsidiaries are linked to internal, external or dual networks. The control variables used here are: size, export, age, share of foreign capital and a set of dummy variables for labor, natural resource, R&D and scale intensive sectors. In the appendix 1, we present the definitions of the constructs in our study.

3.3.3 Estimation methods

To estimate equations 1 and 2, we must correct sample selection bias, which arises when the dependent variable is observed only for a non-randomly restricted sample. In line with previous CDM empirical studies, we estimated a two-step Heckman selection model (Heckman, 1979). In the first step (equation 1), it is estimated the probability that a subsidiary is engaged in R&D activities considering the whole sample of firms and a random-effects probit regression. The equation 2, focused on innovative subsidiaries (those who invest in R&D), uses a random-effects regression and the inverse Mills ratio (generated in step 1) to correct for the selection bias.

Regarding equation 3, it is necessary to correct possible endogeneity problems, since innovation expenditures are endogenous in innovation output equation. Considering this, we use a two-stages least squares estimator (2sls) approach, using the predicted innovation intensity estimated in the first stage of the CDM model (i.e. $\hat{y}_{1it}$) as an instrument of the R&D intensity. The estimation of stage 3 is done to whole sample of firms. Given that the innovation process is a binary indicator, the model is estimated using a random-effects probit regression and calculate the marginal effects at the mean values of the explanatory variables. Additionally, due to product innovation index is a continuous variable the method used is a random effects model. In equation 4, given that the network linkages are binary variables, we used a random-effects probit regression and calculate the marginal effects at the mean values of the explanatory variables. Following Castellacci (2011), in the estimation of all

equations we preferred to use random effects approach instead of fixed effects estimator for a key reason. Random-effects estimator is more efficient than fixed effect estimator as it allows the exploitation of large cross-section variability of dataset with limited time variation, as it is the case of our sample. In fact, due to fixed effects models focuses on the time variation of each unit and ignores information about the cross-sectional variability, it is not capable of estimating the parameters of interest with the appropriate precision.

3.4 Results

The summary statistics are provided in Appendix 2. In order to highlight some previous stylized facts, we first performed an Anova Factor Test to verify whether there were significant differences in innovation performance between subsidiaries with network linkages and isolated subsidiaries. Table III. 2 suggests that a large proportion of foreign subsidiaries in Colombia manufacturing sector are inactive in knowledge networking either internally or externally or both (53% of the total sampled multinational subsidiaries). Also, isolated subsidiaries have a lower performance than those with networking activities and subsidiaries that are dually connected to internal and external networks seem to have a superior innovative performance, followed by those that have internal links. However, the differences are not as large as expected between diverse types of networks.

Table III. 2 Types of networking and subsidiary innovative behavior

Variable	Type of networking				All
	External	Internal	Dual	Isolated subsidiary	
Subsidiaries (%)	43.0	26.3	22.6	53.3	100
R&D engagement (mean)	0.40***	0.38***	0.41***	0.03	0.20
R&D intensity (log) (mean)	3.12***	3.26***	3.31***	1.99	2.80
Process innovation (mean)	0.55***	0.58***	0.59***	0.07	0.29
Product innovation (mean)	0.71***	0.73***	0.75***	0.07	0.36
Product innovation index (mean)	11.9***	13.8***	13.64***	0.84	6.13

Note: *Significant at 10% ** Significant at 5% *** Significant at 1%

Table III. 3 reports the results of the structural model to innovation input and outputs stages. We found that only external linkages with local partners have a positive effect on the likelihood to carrying out R&D activities and on innovation intensity. Interestingly, corporate linkages were not found to have a similar effect on innovation inputs. In contrast, both internal and external linkages have a positive and significant impact on the production of innovations in process and the generation of product innovations with higher degree of novelty. However, marginal effect of external ties on innovation is greater than internal networking. These results mean that Hypothesis H1 is fully supported, but H2 is partially valid.

Table III. 3. Regression results for Hypotheses 1–3

Dependent variables	Innovation inputs				Innovation output			
	R&D engagement		R&D intensity		Process innovation		Product innovation index	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Independent variables								
External linkages	1.458***		8.663***		1.240***		1.369***	
	(0.164)		(0.938)		(0.123)		(0.119)	
Internal linkages	0.118		1.159		0.561***		0.581***	
	(0.155)		(0.789)		(0.141)		(0.110)	
Dual linkages (Interaction term:		0.761***		4.942***		0.971***		0.933***
external × internal)		(0.133)		(0.809)		(0.135)		(0.096)
Control variables								
Age	0.051	0.063	0.482	0.585	0.01	0.029	0.060	0.068
	(0.140)	(0.134)	(0.841)	(0.891)	(0.113)	(0.117)	(0.090)	(0.091)
Foreign capital	-0.006**	-0.008***	-0.031*	-0.046***	-0.001	-0.001	-0.002	-0.002
	(0.003)	(0.003)	(0.017)	(0.018)	(0.002)	(0.002)	(0.002)	(0.138)
Export	0.079	0.116	0.74	0.911	0.069	0.048	0.164*	0.129
	(0.168)	(0.169)	(0.997)	(1.047)	(0.121)	(0.129)	(0.097)	(0.137)
Size	0.305***	0.393***	1.648***	2.390***	0.177***	0.229**	0.152***	0.195***
	(0.064)	(0.066)	(0.377)	(0.410)	(0.046)	(0.050)	(0.038)	(0.038)
Scale intensive sector	0.799***	0.769***	5.194***	5.465***	-0.092	-0.133	0.188	0.129
	(0.237)	(0.226)	(1.324)	(1.408)	(0.166)	(0.168)	(0.142)	(0.137)
Labor intensive sector	0.476**	0.540	3.186**	3.857***	0.239	0.260	0.15	0.200
	(0.236)	(0.228)	(1.344)	(1.430)	(0.164)	(0.168)	(0.131)	(0.128)
R&D intensive sector	0.566**	0.685***	3.617***	4.684***	0.134	0.178	0.241*	0.289**
	(0.221)	(0.213)	(1.291)	(1.371)	(0.161)	(0.161)	(0.128)	(0.129)
R&D intensity (Predicted)					0.012*	0.034*	0.017***	0.037***
					(0.007)	(0.007)	(0.006)	(0.005)
Number of observations	1150	1150	1150	1150	1150	1150	1150	1150
Censored observations			924	924				
Chi-squared (d.f.)	136.7***	97.8***	151.6***	104.4***	200.4***	145.1***	380.1***	293.9***
Method	RE Probit	RE Probit	RE Tobit	RE Tobit	RE Probit	RE Probit	RE	RE

Note: the conditional marginal effects are reported at the sample mean and robust standard deviation in parenthesis.
* Significant at 10% ** Significant at 5% *** Significant at 1%.

Regarding the simultaneity of internal and external linkages, their effects are positive on R&D engagement and innovation intensity. Also, there are positive relationship between dual linkages and the two indicators of innovation performance: process and product innovation. Although, it should be noted that its impact is notably higher for the former, and less relevant in the case of the product innovation index. This suggests that there are possible interdependencies mechanisms between external and internal networks that in time have beneficial effects on subsidiary´s innovation capabilities. Hence, H3 is satisfactory confirmed and these findings would reinforce the dual-embeddedness argument, in line with previous existing evidence.

Table III. 4 reports the results of the random effect probit model thorough which was estimated the likelihood that subsidiaries establish internal, external and dual linkages. The outcome confirms a positive relationship between internal and external network linkages, which supports the hypothesis 4a and then, H4b does not hold. This result confirms that open innovation strategies with external partners are complementary to internal corporate linkages.

Table III. 4. Regression results for Hypotheses 4 and 5

Dependent variables	External linkages	Internal linkages	Dual linkages
	(9)	(10)	(11)
Independent variables			
Internal linkages	1.699***		
	(0.179)		
External linkages		1.501***	
		(0.166)	
Absorptive capacity	3.456***	0.982***	2.048***
	(1.698)	(0.128)	(0.481)
Control variables			
Age	0.153	0.114	0.302*
	(0.113)	(0.134)	(0.162)
Foreign capital	-0.005***	0.004	0.001
	(0.003)	(0.003)	(0.003)
Export	-0.016	0.126	0.097
	(0.147)	(0.157)	(0.175)
Size	0.348***	0.123***	0.303***
	(0.055)	(0.059)	(0.070)
Scale intensive sector	0.119	0.681***	0.728***
	(0.189)	(0.195)	(0.229)
Labor intensive sector	0.154	0.426***	0.326
	(0.193)	(0.212)	(0.238)
R&D intensive sector	0.357***	0.204	0.169
	(0.175)	(0.207)	(0.229)
Constant	Yes	Yes	Yes
Chi-squared (d.f.)	182.8***	151.5***	97.8***
Number of observations	1150	1150	1150

Note: the conditional marginal effects are reported at the sample mean and robust standard deviation in parenthesis.
* Significant at 10% ** Significant at 5% *** Significant at 1%.

Finally, absorptive capacities adopt a positive and significant sign for internal, external and dual linkages. Although, the corresponding coefficient is higher for both external and dual ties. These findings give support to the existence of a self-reinforcing mechanism between networking, innovation performance and absorptive capacities. Considering control variables, it is noted that large subsidiaries are most likely to establish internal and external linkages. Also, those foreign units located in intensive scale and labor sectors are more prone to establish corporate links.

3.5 Concluding remarks and discussion

One of the issues of growing interest in the literature on multinationals enterprises (MNE), is the role played by knowledge sources in the evolution of technological and competitive advantages of foreign subsidiaries and their MNE group. The sources imply external connections, such as those with customers, suppliers, competitors, local universities and R&D labs, while internal sources are found within the MNE network implying relationships with the parent company and other affiliates as well. The development of capabilities through networks is a fundamental factor for the firm's competitive and innovation performance. Despite the importance of the issue for understanding the role of subsidiaries in the MNE network, little attention has been paid to the study of the relationship between different types

of networking activities, internal and external simultaneously, and firms' performance, especially in developing countries.

This study seeks to contribute to understanding the relationship between internal, external and dual linkages, on the innovative performance of the subsidiaries as well as the role of previously accumulated capabilities in this process in the Colombian manufacturing firms. Assuming that different sources of knowledge are likely to have a positive impact on innovation performance, we formulated hypotheses in relation to each source of knowledge. Also, we assess the relationship between internal and external network as well as the role of knowledge absorptive capacity in networking activities.

Although in less developed contexts the access to knowledge is perceived as less valuable than knowledge accessible in more developed countries, which in time reduces the opportunities to enhance subsidiary creative mandates (Narula & Guimon, 2010), our results show that the integration of subsidiaries to internal and external networks is a predictor of subsidiary innovation performance. However, internal and external linkages affect subsidiary performance differently. Whereas external linkages affect innovation inputs and outputs, corporate linkages are only related with innovation outputs. It can be argued that subsidiaries use different sources of knowledge to generate product and process innovations, but the possibility to find subsidiaries that carry out R&D and that are more research intensive, depends much more on their connection to the local innovation system. These findings could contribute to a better understanding of the factors that determine the evolution of subsidiaries toward more creative mandates as well as the creation of competitive advantages at the MNE level.

Also, our results confirm that there are significant complementarities between internal and corporate knowledge linkages. The filial that are simultaneously linked to both contexts have a more active innovative behavior and at the same time there is a positive relationship between them. This suggests that subsidiaries sometimes combine corporate capabilities with external ones for innovation development. In contrast with previous findings (Gammelgaard et al., 2012; Meyer, 2011), it contradicts the view that the external and corporate embeddedness are merely in conflict with one another or subject to a trade-off between them (Ciabuschi et al., 2014).

Finally, accumulation of firms' absorptive capacities defines a self-reinforcing process with networking. We found that the subsidiary knowledge absorptive capacity is a predictor of the likelihood that the subsidiaries are linked to internal and external networks. Consequently, this self-reinforcing process increases the possibility to develop capabilities and competences at subsidiary level and can contribute to the development of capability in the MNC network (Andersson, 2003).

Our results open several possible directions for future research. Ii is necessary to pay more attention to the role of global value chains in the analysis of embeddedness and innovation

performance. Another interesting topic is the effect of subsidiary autonomy on the possibility of the subsidiaries set up internal and external networks to develop innovations.

The results can be of useful to policy makers at local and national levels. Foreign subsidiaries, local firms and R&D organizations can learn and benefit from their linkages with each other, even in a developing economy such as Colombia. Policy makers should stimulate knowledge creation in local networks favoring knowledge sharing. In this process, local organizations could gain access to MNE knowledge through linkages with foreign subsidiaries, this in turn strengthens the knowledge base of the host economy and its competitiveness (Bresciani & Ferraris, 2016). In developing countries as Colombia, these policies will be successful if at the same time policy promotes the development of the scientific and technological base of host countries, for example thorough the development of critical human resources and the upgrading of the scientific system.

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Appendix 3.1

Variables description

Indicator	Definition
R&D engagement	Dummy equal to 1 if the firm invests in R&D during period t.
R&D intensity	R&D investment per employee during period t (in log).
Process innovation	Dummy equal to 1 if the firm has obtained goods or services new or significantly improved during period t
Product innovation index	Weighted index of product innovation by degree of novelty (firm, local market and international level). The weights are defined as the inverse of the share of firms that obtain an output of each specific degree of relevance among the total number of firms obtaining that product innovation.
External network	Dummy equal to 1 if the firm cooperated with clients, suppliers, competitors, universities and R&D centers in innovation activities during period t.
Internal network	Dummy equal to 1 if the firm cooperated with their corporate group (parents and other subsidiaries) in innovation activities during period t.
Dual network	Dummy equal to 1 if the firm cooperated with internal and internal partners in innovation activities during period t.
Absorptive capacity	R&D intensity of the firm divided by the maximum enterprise R&D intensity of the sector to which the company belongs (i.e. the technological frontier) during period t.
Age	Firm age (in log).
Foreign capital	Share of foreign capital in total capital of the firm (%).
Export	Dummy equal to 1 if the firm exported during period t.
Size	Total employees in period t (in log).
Sector dummies (Guerrieri and Milana, 1989)	Dummy equal to 1 if the firm belongs to a R&D intensive sector: ISIC 24, 30, 31 and 33.
	Dummy equal to 1 if the firm belongs to a dummy equal to one if the firm belongs to a scale intensive sector: ISIC 25, 27, 28, 29, 32, 34 and 35.
	Dummy equal to 1 if the firm belongs to a labor-intensive sector: ISIC 17, 18, 19, 22 and 36.
	Dummy equal to 1 if the firm belongs to a natural resources intensive sector: ISIC 15-16, 20, 21, 23 y 26.

Appendix 3.2

Descriptive statistics and pairwise correlations

	Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
(1)	R&D engagement	1.00															
(2)	R&D intensity	0.99	1.00														
(3)	External linkages	0.24	0.22	1.00													
(4)	Internal linkages	0.28	0.29	-0.30	1.00												
(5)	Dual linkages	0.29	0.30	-0.27	0.91	1.00											
(6)	Product innovation index	0.24	0.25	0.15	0.34	0.30	1.00										
(7)	Process innovation	0.29	0.30	0.24	0.38	0.36	0.30	1.00									
(8)	Innovation input-output index	1.00	1.00	0.24	0.31	0.31	0.29	0.34	1.00								
(9)	Absorptive capacity	0.44	0.50	0.01	0.22	0.23	0.15	0.19	0.48	1.00							
(10)	Age	0.14	0.15	0.01	0.18	0.19	0.13	0.14	0.15	0.08	1.00						
(11)	Foreign capital	-0.07	-0.06	-0.13	0.10	0.06	-0.04	-0.02	-0.06	0.02	-0.09	1.00					
(12)	Export	0.09	0.09	0.01	0.10	0.09	0.12	0.07	0.10	0.06	0.14	0.03	1.00				
(13)	Size	0.28	0.27	0.12	0.27	0.26	0.23	0.27	0.29	0.11	0.33	0.03	0.25	1.00			
(14)	Scale intensive sector	0.07	0.08	-0.13	0.15	0.14	0.03	-0.02	0.08	0.02	0.03	0.22	0.06	-0.02	1.00		
(15)	Labor intensive sector	0.04	0.04	0.05	0.03	0.02	0.02	0.09	0.04	0.04	0.07	-0.04	-0.03	0.14	-0.32	1.00	
(16)	R&D intensive sector	0.02	0.01	0.07	-0.02	-0.03	0.03	0.02	0.02	0.03	-0.02	-0.15	-0.03	-0.07	-0.40	-0.34	1.00
	Mean	0.20	-7.97	0.20	0.26	0.23	6.13	0.29	0.00	0.02	3.28	80.89	0.78	5.19	0.27	0.22	0.30
	Std. Dev	0.40	7.21	0.40	0.44	0.42	13.44	0.46	0.99	0.11	0.54	24.71	0.42	1.28	0.44	0.41	0.46

Source: Own calculation based on EDIT IV and EAM (DANE)

Appendix 3.3

Overview of selected studies on the impact of internal and external networks on innovation performance and the interactions between the two knowledge sources

Author	Country	Data	Methods	Innovation performance measure	Effect on innovation of:			External and internal network relationship
					External network	Internal network	Dual network	
Andersson et al (2002)								
Sweden	Interviews in 97 Swedish MNC subsidiaries, 2002	Lisrel model analysis	Product and process innovations	Positive	-	-	-	
Phene& Almeida (2008)	United States	Unofficial survey to 26 subsidiaries of the semiconductor firms, 1981-1992	Negative binomial regression	Patents	Positive	Neutral	-	-
Frenz & Ietto-Gillies (2009)	UK	Community Innovation Survey, 2000	Ordinary Least Squares (OLS) and Heckman model	Innovative sales per employee (log)	Positive	Positive	-	-
Sumelius (2008)	China and Finland	Interviewsin164 subsidiaries, 2000–2002	OLS	Subsidiary Knowledge Development	Positive	Positive	-	-
Garcia Pont et al (2009)	Spain	Case study in one subsidiary of the automotive industry, 1993–2003	Theory building	Subsidiary distinctiveness within the MNC	-	Positive	-	-
Marin & Bell (2010)	Argentina	National Innovation Survey in Argentina, 1998–2001	Anova test applied to types of subsidiaries (dually isolated, corporately integrated, locally integrated and dually integrated)	Composite index with input and output innovation indicators	Positive	Positive	Positive	-
Figueiredo& Brito (2011)	Brazil	Case study in 7subsidiariesof the ICT industry, 1996–2007	Anova test and Duncan's grouping test	Levels of novelty and complexity in innovation.	Positive	Positive	Positive	-
Figueiredo (2011)	Brazil	Case study in 7subsidiariesof the ICT industry, 1996–2007	Mann–Whitney test, Anova test and Duncan's grouping test	Levels of novelty and complexity in innovation.	Positive	-	-	-

Yamin (2011)	Sweden	Unofficial survey to 97 subsidiaries	OLS	Subsidiary's importance for other units' product development	Positive	Negative	-	Negative
Collinson et al (2012)	Taiwan	Case study in 5subsidiariesof the semiconductor sector, 1996–2007	Descriptive and qualitative analysis of patterns of					
Specialization	Revealed innovation capability	Positive	Positive	-	-			
Gammelgaard et al (2012)	UK, Germany, and Denmark	Unofficial survey to 528 firms, 2007-2008	Partial least square (PSL) to structural equation modeling	Productivity	Positive	Positive	-	Positive

Overview of selected studies on the impact of absorptive capacity on subsidiary´s internal and external network

Author	Country	Data	Methods	Network measure	Effect of absorptive capacity on:		
					External network	Internal network	Dual network
Figueiredo (2011a)	Brazil	Case study in 7subsidiaries in ICT industry, 1996–2007	Anova test and Duncan's grouping test	Levels of novelty and complexity in innovation RARO	Positive	Positive	Positive
Holl & Rama (2014)	Spain	Tecnological Innovation Panel PITEC	Probit model	R&D outsourcing and cooperation	Positive	-	-
Golebiowski (2015)	Germany, Czech Republic and Romania	Community Innovation Survey, 2006-2008	Maximum matching estimation (AMOS)	-External innovation cooperation -Internal innovation cooperation	Positive (Czech Republic)/negative (Rumania)	Positive (Germany and Romania)/neutral (Czech Republic)	-

CHAPTER IV. ESTIMATING TECHNOLOGICAL SPILLOVER EFFECTS IN PRESENCE OF KNOWLEDGE HETEROGENEOUS FOREIGN SUBSIDIARIES

4.1 Introduction

Technological spillovers from foreign direct investment (FDI), is a topic that has long been studied as a way to assess the role of multinational enterprises (MNEs) in the economic development of countries. Beyond direct benefits in terms of job creation, levels of capital, and national spending on innovation, FDI could contribute to enhancing productivity and the competitiveness of domestically owned firms through the generation of positive externalities, including technology spillover. Regarding developing countries, foreign subsidiaries have the potential to permit not only greater access to technological skills generated abroad, but the possibility of deeper connections to the global process of creation and dissemination of knowledge (Marin & Arza, 2010; Pietrobelli & Rabellotti, 2010). At the same time, under certain circumstances, inward FDI may exacerbate the problems caused by technological dependence in developing countries and generate unwanted effects, such as crowding-out the demand for local firms (Aitken & Harrison, 1999).

Despite this being a widely studied subject, empirical evidence on the existence of knowledge spillovers from FDI remains contradictory and inconclusive, revealing remarkable differences between countries. One reason that may explain the weakness of the evidence are the basic assumptions underlying the classic model on spillovers. In this line, a recent branch of literature has emphasized that foreign subsidiaries do not exhibit homogeneous technological behaviour, and that their differences can determine the generation of different spillover effects on the domestic economy (Castellani & Zanfei, 2005; Marin & Bell, 2006; Marin & Sasidharan, 2010; Giroud *et al*., 2012; Crescenzi *et al*., 2015).

These arguments are supported by international business (IB) contributions, arguing that subsidiaries are not homogenous units but that they follow different strategies or mandates, also in terms of knowledge creation. This is since MNEs have granted specific mandates to the subsidiaries, or may be the result of their evolution toward more active innovative behaviour (Birkinshaw & Hood, 1998; Nobel & Birkinshaw, 1998; Cantwell & Mudambi, 2005). The above contrasts with the traditional approach, in which subsidiaries assume a passive role in the process of generation and transfer of knowledge from the parent to domestic firms – i.e., their technological activities are only a reflection of decisions of the MNE's parent company abroad (Vernon, 1966; Hakanson, 2014).

Following these arguments and prior empirical evidence, this paper contributes to the literature with an empirical analysis that highlights the relevance of the technological heterogeneity of foreign subsidiaries in the generation of intra-industry knowledge spillovers in a developing context, exploring the beneficial effects to domestically owned firms in Colombia. The identification of types of subsidiaries according to their technological responsibilities is undertaken in a first step. Secondly, we estimate the differential effect on the total productivity of domestic firms using firm-level panel data covering the period 2003 to 2012. The findings reveal the inexistence of conventional spillovers, and that these effects are more likely generated in presence of creative subsidiaries.

Colombia is a country with a long history of inward FDI-attraction policies; however, further technological acquisition from foreign companies has not been a major concern. Until now, political attention has been concentrated on the amount of inward FDI in the national economy, supported in horizontal policies, rather than on the attraction of kinds of MNE that contribute with greater value added activities. In addition, although Colombia is not among those countries actively involved in the international generation of technology, the contribution by foreign subsidiaries to innovation investments in Colombian manufacturing sectors is significant (Albis & Alvarez, 2014). Therefore, this country provides an interesting case study that can contribute to the present state of knowledge about the effects that foreign-owned firms may generate on local innovation capabilities in less developed contexts.

The remainder of this paper is structured as follows. The second section presents the theoretical framework and the development of our hypothesis. The third section contains the description of data sources, the empirical model, and the research method. A discussion of results is presented in fourth section, and the fifth section includes some concluding remarks and basic implications.

4.2 Theory and hypothesis

4.2.1 The classic approach on technological spillovers

Since the pioneering research developed in the 1970s (e.g. Caves, 1974; Globerman, 1979), the study of knowledge spillover effects has been subject to extensive attention in the literature, in both developed and developing economies. The concept of spillover effects involves the idea that the technology of an MNE – including product technologies, processing and distribution, management and marketing skills – might be transmitted to domestic firms and, therefore, lead to increases in levels of productivity (Blomström & Kokko, 1998). The general assumption has been the existence of knowledge and technological development gains that multinational companies cannot appropriate abroad, and that are transmitted to the host economy. The channels through which the presence of foreign subsidiaries might affect the technological and productive performance of domestically owned firms have been identified as diverse: involuntary technology transfer through imitation and demonstration

effects, the mobility of qualified personnel, and the transfer of knowledge to domestic firms via their connection to the subsidiaries' value chain, as well as competition effects that induce the efficiency or technological improvement of domestic firms (Blomström & Kokko, 1998; Crespo & Fontoura, 2007).

Despite the widespread attention to the issue, there is insufficient evidence around the generation of spillover effects (Crespo & Fontoura, 2007; Greenaway & Kneller, 2007; Smeets, 2008; Meyer & Sinani, 2009; Perri & Peruffo, 2016). While the pioneering studies on the topic based on industrial and cross-section data found that FDI had positive effects on domestic firms' productivity (e.g. Caves, 1974; Globerman, 1979), more recent research, using firm and panel data, have not managed to replicate the positive results of previous studies in a wide range of countries. To address this, the literature has turned its attention to certain factors that may affect the generation of spillovers, emphasizing: the importance of the knowledge-absorptive capacities of domestic enterprises as a precondition to capturing the benefits of FDI (Cantwell, 1989; Girma, 2005); the different channels that lead to the transfer of knowledge, particularly forward and backward linkages (Javorcik, 2004); and the role of spatial dimension on knowledge spillovers (Driffield, 2006).

While these contributions to the general model have permitted a better understanding of the subject, little attention has been given to restrictive assumptions about the technological behavior of foreign subsidiaries for the assessment of spillover effects (Castellani & Zanfei, 2005; Marin & Bell, 2006; Marin & Sasidharan, 2010). In the main approach, MNEs have by definition the potential to generate positive impacts on indigenous technological capabilities, based on three basic assumptions. First, the technological superiority of multinational companies, derived from the possession of unique intangible assets (e.g. technology, management skills) that partly explain the raison d'être of multinationals (Hymer, 1976; Dunning, 1988), it being assumed that these intangibles will be automatically replicated in the subsidiaries and represent a potential source of positive effects for domestic firms. Second, that technological assets are generated centrally in MNEs and that the role of foreign subsidiaries consists merely in the adoption and diffusion of the technology generated in the parent companies (Cantwell, 1995; Zanfei, 2000). This view is consistent with an earlier theory of the product cycle model by Vernon (1966), according to which strategic decisions, including R&D activities, are strongly centralized in the home country, and the aim of foreign investment is to facilitate the implementation of less beneficial stages of the product life cycle, incorporating more accessible and standardized technology in the MNE (Cantwell & Janne, 1999; Zanfei, 2000). Finally, the third assumption is that knowledge is a public good easily transferable among MNE units (Marin & Arza, 2010), it being generally assumed that foreign subsidiaries face homogeneous conditions and similar absorptive capacities to assimilate and transmit the knowledge of the parent companies in host economies.

4.2.2 The changing role of foreign subsidiaries

Competitive pressures derived from the globalization of markets and production, and the deep changes in the generation of technology on an international scale, are challenging the validity of conventional assumptions about the innovative behavior of foreign subsidiaries and their role in the creation of value inside the MNE (Archibugi & Michie, 1995; Carlsson, 2006; Dunning & Lundan, 2009; Belderbos *et al*., 2013). Although many technological activities are still located at home,[8] MNEs have evolved toward less hierarchical organizational structures that are based on integrated technology networks, which allows them to more efficiently coordinate their diversified and geographically disperse innovation activities and capacities, both within the organization and with other actors at a global scale (Hedlund, 1994; Cantwell, 1995; Cantwell & Janne, 1999; Zander, 2002; Iammarino & McCann, 2013).

Following the above arguments, several studies have found a variety of patterns of technological innovative activities in foreign subsidiaries, observable both in developed countries (Florida, 1997; Pearce, 1999; Bas & Sierra, 2002; Cantwell & Mudambi, 2005; Álvarez & Cantwell, 2011) and in the developing world (Ariffin & Figueiredo, 2004; Figueiredo & Vedovello, 2005; Sargent & Matthews, 2006; Hobday & Rush, 2007; Bell *et al*., 2008; Galina *et al*., 2011). This stream in the literature finds that technologically active subsidiaries in host countries generate new knowledge beyond those generated centrally in the MNE's headquarters and could make important contributions to the MNE's competitive advantages.

Subsidiaries might specifically pursue different strategies or mandates, whether in the creation or exploitation of competences, alluding to the allocation of responsibilities in the value chain and, particularly, in the generation of new knowledge (Cantwell & Mudambi, 2005). Competence-exploiting (CE) subsidiaries are associated with the classic view of this type of organization, with innovative activities being mainly directed toward the adaptation of products and processes to local market conditions. In this category, it is also possible to find subsidiaries with little or no commitment to innovation, especially in least-developed countries (Balcet & Evangelista, 2005; Marin & Bell, 2010). In contrast, competence-creating (CC) subsidiaries have a more active role in the generation of new products and services in international markets, and a stronger connection between local and global knowledge bases to develop their innovation activities.

Three main drivers in the configuration of a more strategic role for subsidiaries are identified in the related literature: (i) local environment factors in the host country, such as their technological dynamism, industrial specialization, and changes in economic conditions (Florida, 1997; Frost *et al*., 2002; Cantwell, 2009); (ii) the assignment by headquarters as

[8] The concentration of innovative activities in the home country can be justified by its strategic nature, by the existence of strong scale and scope economies in R&D, by the high coordination costs of international innovation activities across national borders, and by the role of the home innovation system in supporting the generation and dissemination of knowledge (Cantwell, 1995; Pavitt & Patel, 1999).

part of a strategy to maintain or increase the corporation's competitive advantages (Dunning & Narula, 1995; Florida, 1997; Papanastasslou & Pearce, 1997; Kuemmerle, 1999; Cantwell & Mudambi, 2005); or (iii) the choice or evolution of subsidiaries in favor of the development of specialized skills (Birkinshaw & Hood, 1998; Nobel & Birkinshaw, 1998). These factors interact with each other and their configuration can determine the progress or decline of the subsidiaries within the corporation; some simply maintain their competence-exploiting mandate (e.g. assembly for production), while others may assume a more creative role and thereby increase the level and complexity of their innovative activities (Cantwell & Mudambi, 2005).[9]

More recent studies highlight that innovation capability building is also the result of a complex processes of interaction, both within the firm and between the firm and external actors (Figueiredo, 2011; Achcaoucaou, 2014; Ciabuschi *et al*., 2014). In this context, more creative subsidiaries could play a more prominent role in knowledge transfer processes within the MNE network and then to the local economy, due to their greater capacity of learning (Frost, 2001). At the same time, the knowledge-absorptive capacity of subsidiaries – understood as the firm's ability to identify, assimilate, and exploit knowledge from the environment (Cohen & Levinthal, 1990) – is a key factor to improving knowledge flows between organizational units of the MNE and to assimilation of external knowledge (Gupta & Govindarajan, 2000; Monteiro *et al*., 2008; Lee & Wu, 2010; Gammelgaard *et al*., 2012).

4.2.3 Spillovers and technological heterogeneity of subsidiaries

In the presence of subsidiaries with heterogeneous technological capabilities, it is necessary to review the conditions and channels that lead to knowledge spillovers from foreign firms in host economies. This has given rise to the emergence of a new body of spillover literature centered on subsidiaries, in opposition to the traditional conceptualization focused on the headquarters (Marin & Arza, 2010; Ha & Giroud, 2015). The general approach of these studies is that the quality and the level of the subsidiaries' technological activities would have different knowledge externalities beneficial for domestic firms.

In the presence of more creative foreign subsidiaries, stronger knowledge spillovers to domestically owned firms can be generated thanks to the potential for knowledge diffusion, through the qualified personnel linked to the innovation activities of subsidiaries. Scientists and engineers in competence-creating subsidiaries have greater employment and learning opportunities compared to workers in subsidiaries with fewer innovative activities (Kuemmerle, 1999), and this may be a source of knowledge diffusion via formal and informal contacts with local engineers or scientists, or via labor mobility toward domestic firms (Todo & Miyamoto, 2006).

[9] Evidence on the evolution of subsidiaries in developing countries is provided by Ariffin & Bell (2014) in the case of Malaysia, Hodday & Rush (2007) for Thailand, Sargent & Mattews (2006) for Mexico and Collison & Wang (2002) for Taiwan.

On the other hand, when foreign subsidiaries are engaged in innovation activities, there are greater opportunities for imitation and learning, not only in terms of knowledge developed elsewhere by the MNE, but also in the sense of new knowledge generated by the subsidiaries themselves (Castellani & Zanfei, 2005). Is also argued that in host economies which have achieved a certain level of development (i.e., that have a smaller technology gap with respect to the MNE), creative subsidiaries can spread valuable technologies that may not have been previously present in these economies; meanwhile, exploiting subsidiaries (with a smaller technology gap) may create competitive pressures that displace the domestic demand (Marin & Sasidharan, 2010). The competition effect created by creative subsidiaries may force domestic firms to improve their competitive advantages through imitation, or through development of their own technologies, in order to compete in local and global markets (Ha & Giroud, 2015).

Also, innovation activities might require the introduction of R&D inputs or might induce technological cooperation with domestic counterparts. Evidence shows that competence-creating subsidiaries are more connected to the local economy, where knowledge transfer between the subsidiary and domestic firms can be more intense than is the case with less knowledge-intensive intermediate goods (Castellani & Zanfei, 2005). In fact, several studies have shown that it is more likely among subsidiaries with higher innovation capacities to establish linkages with local actors, such as customers, suppliers, and R&D organizations, to develop their innovation activities (Boehe, 2007; Figueiredo & Brito, 2011; Golebiowski, 2015); and this fact would enhance the probability of generating positive technological externalities to the local economy through knowledge linkages.

In general, empirical evidence shows that active technological subsidiaries generate higher positive technological externalities than those with lower innovation capacities (i.e., FDI spillovers are influenced by the strategic role of the subsidiaries in the MNE's network). In Indonesia, Todo & Miyamoto (2006) found that only subsidiary companies that conducted R&D and training generated positive effects on domestic firms' productivity. In a similar way, Marin & Costa (2010) provide evidence about positive effects of FDI on a local economy, when subsidiaries in Brazil were active in the production of knowledge and showed higher human capital levels. In Argentina, Marin & Bell (2006) found that positive knowledge spillovers from foreign firms could only be observed in manufacturing sectors where foreign subsidiaries exhibited high technological activity. In Italy, Castellani and Zanfei (2005) concluded that positive spillovers to domestic firms were produced when foreign affiliates carried out knowledge-intensive activities and when they were long established in the host country. Marin & Sasidharan (2010) provide evidence that only creative-competence subsidiaries produce positive spillover effects to domestic firms in India, while subsidiaries that exploit competences, or that are not involved in any technological activity, have negative spillover effects. Similarly, Ha & Giroud (2015) have found in Korea that the activities of competence-creating subsidiaries generate significantly different horizontal and vertical spillovers, compared with competence-exploiting activities.

Foreign subsidiaries are, in sum, technologically heterogeneous, and they are not passive actors within the MNE. Therefore, they do not provide homogeneous opportunities for the generation of knowledge spillovers in host economies. A minimal innovation capacity is required to be an effective channel for transfer and adaptation of the knowledge generated in the MNE network, or to generate novel innovation activities and disseminate them to domestic firms. Subsidiaries can also evolve to develop new technological skills. Given this, our research objective is to empirically test the hypothesis that *more creative subsidiaries generate greater positive host country spillover effects, in the same sector, than subsidiaries that only exploit the competences centrally generated in the multinational corporation*.

4.3 Methodology

4.3.1 Data

The empirical analysis presented in this study is based on a firm-level panel data resulting from the intersection of two sources collected by the National Statistics Department of Colombia (DANE):[10] the Annual Manufacturing Survey (*Encuesta Anual Manufacturera*, henceforth EAM) and the Development and Technological Innovation Industrial Survey (EDIT, its Spanish acronym), in versions II to VI.[11] The former is a survey that can be considered a census of the Colombian manufacturing sector, and it provides general economic data on firm characteristics and performance variables such as sector of activity,[12] legal organization, sales, added value, employment, expenditures, fixed assets, and trade, among others. The EAM includes information from industrial establishments with ten or more employees, or with a level of production higher than the specific value stipulated as a reference for each year.[13]

The second dataset, based on the Oslo and Bogotá Manuals, collects two-year information about innovation activities undertaken by industrial firms according to the directory of firm establishments in the EAM. By merging the EDIT and EAM surveys, we added information on variables related to investment in innovation activities, which are registered for each year.[14]

[10] The firm-level data provided by this agency are subject to strict regulation of the statistical reserve. Hence, the data were worked directly at DANE's offices through the signing of a specific agreement of collaboration.
[11] The pilot version of the survey was conducted in 1996. In this research, we use the following versions of the survey: EDIT II (2003–2004), EDIT III (2005-2006), EDIT IV (2007-2008), EDIT IV (2009-2010) and EDIT VI (2011-2012).
[12] The survey uses the International Standard Industrial Classification (ISIC Rev. 3) adapted to Colombia by DANE.
[13] For example, for 2012 this value was $136.4 million in constant pesos (approximately US$ 45,000).
[14] The two databases have common firm identifiers, which allow their combination for research purposes.

After a process of cleaning the database to correct for inconsistencies, missing values, and errors in the collection of information, we obtained an unbalanced panel with 66,448 observations and 11,419 firms for the period 2003-2012.[15] Table IV. 1 shows the main characteristics of the database, distinguishing between MNE subsidiaries and domestic firms. The set of MNE subsidiaries in the database is composed of 579 firms, with the domestic firms being around 10,840. Regarding the definition of foreign firms in our dataset, the cutting-off point is delimited at a level of 25 percent foreign ownership of the firm.

Table IV. 1. Panel data characteristics

Time: 2003-2012	Foreign subsidiaries	Domestic firms	All firms
Observations	4,388	60,487	66,448
Firms	579	10,840	11,419
Consecutive observations by firm (average)	6.1	7.6	6.4

Source: Own calculation based on DANE - EDIT and EAM.

4.3.2 Identifying types of subsidiaries

Prior to specification of the spillover evaluation model, we identified types of affiliates according to their technological responsibilities, i.e., whether they can be classed as competence-creating or -exploiting units. Literature contributions allowed us to identify various elements that define creative subsidiaries (CC subsidiaries), including: (i) the development of innovation activities that generate new technological assets and capabilities that will allow the MNE to acquire or maintain competitive advantages (Dunning & Narula, 1995; Florida, 1997; Kuemmerle, 1999); (ii) the subsidiary connections with external markets (Cantwell & Mudambi, 2005; Álvarez & Cantwell, 2011); and (iii) greater linkages with the host innovation system and with other units of the international corporation, i.e. dual-network embeddedness (Marin & Bell, 2010; Figueiredo, 2011; Collinson, 2012; Achcaoucaou, 2014).[16] Based on these specific features, the identification of subsidiary types has been based on the following four indicators (See Appendix 1 for more details):[17]

[15] In cleaning the database, several aspects have been taken into account: (i) to exclude firms with missing or zero values in any of the main variables of interest during the observation period; (ii) data imputation using the Hot Deck method in the case of missing 0 zero values between two years; and (iii) to exclude sectors with zero or low and discontinuous foreign presence at regional level.

[16] Other factors, not considered here, are the technological intensity of the sector where the subsidiaries are located (Narula, 2002), or where the recipient countries have already achieved considerable technological competences (Bell & Marín, 2004; Molero & Garcia, 2008).

[17] We are aware that the innovation database displays significant error measure problems in the levels of innovation expenditures across years, due to methodological changes in the survey between 2003 and 2007. Hence, we do not distinguish between levels of expenditures. Instead, we use a discrete measure that equals 1 if the firm invests in R&D.

- *R&D engagement*: dichotomous indicator that measures the existence of research and innovation capabilities within subsidiaries.
- *Export engagement*: dichotomous variable that attempts to measure the subsidiaries' connection with global markets.
- *Local embeddedness index*: using factor analysis, we construct an index that takes into account the local sources of information to innovate (such as suppliers, clients, competitors, and R&D organizations (i.e., universities and R&D centers). Here, the firms' sources of information for innovation activities can be seen as a proxy of knowledge flows within and across organizations (Criscuolo, 2010).[18]
- *MNE embeddedness index*: seeks to measure knowledge flows between subsidiaries and their multinational groups (headquarters and other units within the multinational). The index is obtained by applying a factor analysis.[19]

In order to identify types of foreign subsidiaries, we use Ward's hierarchical classification methodology to generate two clusters of subsidiaries with homogeneous characteristics and with 'distances' between them as wide as possible. Table IV. 2 shows the distribution of competence-creating (CC) and competence-exploiting (CE) subsidiaries, as well as the average value of the variables used in the classification.

Table IV. 2. Clusters of subsidiaries and classification variables (on average), 2003-2012

Indicator	**Competence-creating (CC)**	**Competence-exploiting (CE)**
Firms	189	390
1. R&D engagement (1/0)	0.27	0.08
2. Export engagement (1/0)	0.78	0.68
3. MNE embeddedness index	0.40	-0.16
- Headquarters (1/0)	0.56	0.24
- Other enterprises within the MNE group (1/0)	0.46	0.20
4. Local embeddedness index	0.59	-0.24
- Clients (1/0)	0.70	0.28
- Suppliers (1/0)	0.62	0.27
- Competitors (1/0)	0.68	0,28
- R&D organizations (1/0)	0.51	0.21

Source: Own calculation based on DANE - EDIT and EAM.

The share of competence-exploiting and competence-creating subsidiaries on sales and their distribution by sector is presented in Table IV. 3. The number of competence-exploiting subsidiaries in the Colombian manufacturing industries is higher than that of competence-creating units, and the industries with a greater share of competence-creating subsidiaries are those with medium-to-high technological intensity, such as vehicles, chemical products, and machinery and equipment.

[18] The result of factor analysis generated one factor with an eigenvalue over 1 and an explained variance of 98%.
[19] The one extracted factor has an eigenvalue over 1 and an explained variance of 96%.

Table IV. 3. Foreign presence across sector and types of subsidiaries (as a percentage of total sales)

Sector	Competence-creating	Competence-exploiting	All subsidiaries
Food, beverages & tobacco	12.9	9.6	22.3
Clothing and apparel	2.1	14.7	16.8
Leather and related products	3.6	7.9	10.9
Transport equipment	2.4	27.5	29.9
Printing	1.2	7.5	7.8
Electrical machinery & equipment	7.6	38.5	46.0
Other machinery and equipment	17.3	9.4	26.4
Non-metallic mineral products	9.0	3.0	11.9
Other manufacturing	1.9	12.1	13.6
Paper and paper products	11.7	10.1	21.0
Rubber & plastic products	12.0	16.4	28.5
Basic metals	3.3	17.9	21.2
Metal products	3.1	33.5	36.5
Chemical products	23.1	29.4	52.2
Textile industry	9.5	9.8	18.6
Vehicles	55.8	15.7	71.2

Source: Own calculation based on DANE - EDIT and EAM.

4.3.3 Model and method

To assess the presence of FDI knowledge spillovers from multinationals firms, we follow a two-step procedure. First, we estimate total factor productivity (TFP) for each manufacturing sector and the sample of domestic firms.[20] Second, we examine the relationship between the productivity of domestic firms and the foreign presence, distinguishing the effect by types of foreign subsidiaries, as established in the previous section.

In the first stage, the productivity of each firm is estimated using a production function approach. We assume a log-linear transformation of a Cobb-Douglas function, of the following type:

$$y_{it} = \beta_0 + \beta_l l_{it} + \beta_k k_{it} + \beta_m m_{it} + \omega_{it} + \varepsilon_{it} \qquad (1)$$

where lower-case letters in Eq. (1) refer to natural logarithms, and subscripts *i* and *t* refer to firm and year, respectively. Here y_{it} represents the real output of the firm; and l_{it}, k_{it} and $m_{it}$are inputs of labor, capital and raw materials, respectively. The term ω_{it} represents total factor productivity (TFP) and ε_{it} is an i.i.d. component, representing unexpected deviations from the mean due to measurement error, unexpected delays or other external circumstances.

The firm's output is defined as valued added deflated by industry-specific producer price indices at the two-digit ISIC classification. We distinguish two types of labour: (1) unqualified personnel corresponding to blue-collar workers and operators, and (2) qualified personnel, defined as the sum of professionals, technicians and sales and administrative staff.

[20] This is intended to prevent the dynamics of estimated TPF to be influenced by the productivity of foreign subsidiaries (Castellani & Zanfei, 2005).

The material input is defined as the consumption of raw materials deflated by the producer price index of materials. The stock capital is defined as the value of fixed assets at the beginning of the year deflated by the simple average of the price deflators for terrains, buildings and structures, machinery and equipment, transport equipment and office equipment.

To estimate TFP we follow the semi-parametric method introduced by Levinsohn and Petrin (2003). This approach uses intermediate inputs as proxy for unobserved productivity shocks to take account of possible endogeneity problems resulting from the high correlation between these shocks and the levels of inputs used in production.[21] In the second stage, we began by defining a general model for the determinants of total factor productivity of domestic firms in function to a measure of foreign investment. The model takes the following form:

$$\ln TFP_{it}^{d} = \alpha_0 + \alpha_1 \ln FDI_{jt} + \boldsymbol{\alpha_2 X_{it}} + \mu_t + \varepsilon_{it} \qquad (\boldsymbol{2})$$

Where the subscripts *i, j* and *t* in Eq. (2) refer to firm, sector and year, respectively. The variable $\ln TFP_{ijt}^{d}$ is the logarithm of the multifactorial productivity of domestics firms; $\mathrm{FDI_{jt}}$ captures the extent of foreign presence in sector *j* at time *t,*; and $X_{ijt}$is a vector of relevant control variables. Whereas parameter α_1 captures the effect of spillovers from foreign firms, μ_t denotes unobservable time-invariant firm-specific effects, and $\varepsilon_{\mathrm{it}}$ is the error term.

The hypothesis that technologically active foreign subsidiaries have a higher spillover potential is tested by estimating a further modification of Eq. (2), including a measure of the effect of different types of FDI (different types of subsidiaries) on domestic industry productivity. The model that we estimate adopts the following form:

$$\ln \mathrm{TFP_{ijt}^{d}} = \alpha_0 + \alpha_1 \mathrm{CC\_FDI_{jt}} + \alpha_2 \mathrm{CE\_FDI_{jt}} + \boldsymbol{\alpha_3 X_{ijt}} + \mu_t + \varepsilon_{\mathrm{it}} \qquad (\boldsymbol{3})$$

In Eq. (3), $\alpha_1$and α_2 capture the external effect on domestically owned firms of foreign competence and exploiting subsidiaries, respectively. We calculate 'creating' and 'exploiting' FDI as follows:

$$\mathrm{CC\_FDI_{jt}} = \left[\sum_{\forall i \in j} Foreign\ Share * Y_{it} * CC\ dummy\right] / \sum_{\forall i \in j} Y_{it} \quad (\boldsymbol{4})$$

$$\mathrm{CE\_FDI_{jt}} = \left[\sum_{\forall i \in j} Foreign\ Share * Y_{it} * CE\ dummy\right] / \sum_{\forall i \in j} Y_{it} \quad (\boldsymbol{5})$$

[21] To estimate productivity, we use the Stata routine *levpet* developed by (Petrin *et al*., 2004) and estimate firm-level production functions separately for 22 manufacturing sectors. In the interest of brevity, the results of this estimation are not included here, but are available upon request.

Three control variables are included in the vector $\boldsymbol{X}$. The first is the Herfindahl index, calculated as the sum of squares of firms' turnover shares in each 2-digit industry. This allows us to control for the effect of technological changes generated by domestic firms in response to increased competition from FDI, rather than from technology flows. The second is the domestic firm's knowledge-absorptive capacities, a dummy variable which seeks to take into account the hypothesis that the foreign presence is more likely to generate spillover effects when domestic firms have strong innovation competences and consequently higher knowledge-absorptive capabilities. Finally, we included firm size and export engagement as control variables.

To the estimation of equation (3), we used a random-effects approach instead of fixed-effects estimator, because this method is considered more efficient in the presence of independent variables that do not vary much over time (Beck, 2001; Plümper & Troeger, 2007). In fact, random-effect estimators allow the exploitation of large cross-section variability of datasets with limited time variation, as it is the case with our sample. In contrast, due to the focus of fixed-effects models on the time variation of each unit, information about cross-sectional variability is ignored, and these models are not capable of estimating the parameters of interest with appropriate precision (Castellacci, 2011).

4.4 Results

The empirical results obtained under different specifications are shown and discussed in this section. Appendix 2 presents the descriptive statistics and the correlation matrix for the regression variables, based on the full sample of domestic-year observations. In general terms, the presence of any major problem of multicollinearity among the independent variables was not observed.

The outcomes to the conventional spillover model in which FDI is treated simply as a homogeneous block are reported in column (1) of Table IV. 4. We did not find a statistically significant relationship between foreign presence and domestic productivity of Colombian firms within the same sector. That is, there were no horizontal spillovers when we considered the conventional model to measure the productivity effect of FDI. This is consistent with previous evidence for Colombia (Kugler, 2006; Hyman, 2011) as well as for other less development countries (Haddad & Harrison, 1993; Aitken & Harrison, 1999).

Among the controls, some are significant and the signs of the estimated coefficients are coincident with theoretical expectations. Spillovers are more likely when domestic firms are large and they are engaged in R&D activities, this serving as a good indicator of knowledge generation and also revealing higher absorptive capacities. On the other hand, firms' linkages to foreign markets through international trade is another aspect that would reinforce the 'learning by exporting' argument as the market power approached by a market concentration variable.

In a second round of estimations, the results change substantially when the presence of technologically heterogeneous subsidiaries is explicitly considered, according to recent calls about the role of subsidiary in IB literature (Giroud, 2012; Marin & Sasidharan, 2010); that is to say, distinguishing between the effects of competence-creating and competence-exploiting subsidiaries, respectively. From column (2) we gather that only competence-creating FDI in Colombia has a consistent positive effect on the productivity of local firms, while competence-exploiting FDI does not have any statistically significant effect. These results also reveal that the effect is more likely in those industries with a higher market concentration. Meanwhile, it can be said that the significant sign of the estimated coefficient of CE-FDI in column (2) could be related to the negative effect that a higher exposure to competition generates, and to the fact that these subsidiaries are more market-oriented; this is opposed to the case of more creative activities, in with CC subsidiaries.

Table IV. 4. Results of conventional and subsidiary heterogeneity model of productivity spillovers

Dependent variable: TFP (log)	**Conventional spillover model (1)**	**Subsidiary heterogeneity model (2)**
Conventional FDI	-0.068	
	(0.001)	
Competence-creating FDI		0.056***
		(0.005)
Competence-exploiting FDI		-0.018*
		(0.010)
Market concentration	0.004	0.006*
	(0.003)	(0.003)
R&D engagement	0.076***	0.075***
	(0.012)	(0.012)
Export engagement	0.150***	0.153
	(0.009)	(0.009)
Size (Log employment)	0.769***	0.759***
	(0.005)	(0.005)
Constant	Yes	Yes
R2 overall	0.60	0.61
R2 between	0.63	0.64
R2 within	0.12	0.12
Wald chi2	9.747***	10.084***
Observations	60,487	60,487
Firms	10,840	10,840
Method	Random effects	Random effects

Note: Standard errors in brackets. * p<0.1, ** p<0.05, *** p<0.01.

These results are consistent with previous evidence (shown in section 2.3) but also allow us to confirm our hypothesis, according to which creative subsidiaries in Colombia imply a higher potential for the generation of spillovers within industries – an argument that can be easily extended to the case of other developing host countries.

On the other hand, the variables of R&D and export engagement, as well as of market concentration and size, are also statistically significant and adopt the expected signs. These

findings are in line with the hypothesis that spillovers are more likely in the presence of higher absorptive capacities, in this case reflected by the R&D engagement of firms according to the original definition provided by the seminal contribution of Cohen and Levinthal (1989), as well as by export engagement, which may induce 'learning by exporting' opportunities (as was shown in a recent paper by Albis & Alvarez (2014)) where a greater similarity was found between the innovative behaviour of foreign subsidiaries and those Colombian firms involved in exports.

4.5 Concluding remarks

There are a vast number of studies focused on analysis of whether the presence of foreign direct investment leads to the generation of horizontal technological spillovers toward domestic firms in host countries. Meanwhile, FDI-attraction policies continue to be defined by many governments assuming the generation of positive effects without discrimination. However, until now, the empirical evidence has not led to a full consensus on the subject. One possible reason for these inconclusive results may be the rigid assumptions that underlie the classic model for assessing spillover effects, where subsidiaries are considered to be passive actors in the processes of generation and transfer of knowledge. Recent evidence from IB literature suggest that foreign subsidiaries can develop distinctive capabilities by combining resources via own-initiative, host-country endowments and internal MNE networks, and these distinctive capabilities may determine the possibility and generation of technological spillovers in host economies.

Based on these arguments, the main contribution of this research is to extend existing discussions about the role of subsidiary heterogeneity in FDI spillovers, and to provide fresh new evidence based on the empirical testing of differential intra-industry spillover effects of technologically heterogeneous foreign subsidiaries on total factor productivity of domestically owned firms, using firm-level panel data for manufacturing firms in Colombia for the period 2003-2012. We propose a specific typology of subsidiaries according to their innovation, export, and networking capabilities, then analyze the importance of each in explaining knowledge spillover effects. The empirical results confirm the hypothesis that competence-creating subsidiaries generate greater positive productivity effects on domestic manufacturing firms, within the same sector, than do units identified as competence-exploiting. In fact, subsidiaries oriented mostly to technologically exploitative activities do not generate knowledge spillover effects. In contrast, the estimation of the conventional model of spillover effects, where foreign investment is treated as a homogenous block in terms of technological capabilities, shows that the empirical analysis does not yield statistically significant results. These findings also reveal the limitations of considering subsidiaries as a homogeneous group with passive technological behavior, for the purposes of both research and public policy.

Policy makers in many developing economies spend substantial resources on attracting inward investment, expecting that FDI inflows will provide productivity and knowledge

spillovers from more productive MNEs. However, the contribution of this research is to show that not all subsidiaries generate *per se* the same knowledge externalities beneficial to domestic firms, with important implications suggesting that more attention should henceforth be paid to the characteristics of FDI and its motivations in order to improve the effectiveness of public support and to achieve specific development objectives. Assuming the dynamics of foreign subsidiaries that may evolve toward more creative strategies in the host locations, it is also plausible to consider the existence of a mismatch between policy actions oriented toward providing a mechanism to guarantee the rise of absorptive capacities in domestic firms with a more pro-innovation environment for foreign units.

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Appendix 4.1

Definition of variables (Firs step)

Variable	**Definition**
Dependent variable	
Added value	Logarithm of added value deflated by the producer price index
Independent variables	
Capital stock	Logarithm of book value of the capital of the firms deflacted by the price index of terrain, buildings and structures, machinery and equipment, transport equipment and office equipment.
Blue collar workers	Logarithm of the sum of workers and operators
White collar workers	Logarithm of the sum of professionals, technicians and sales and administration staff
Materials	Consumption of raw materials deflated by the producer price index of raw materials

Definition of variables (Second step)

Variable	**Definition**
Dependent variable	
Total Factor Productivity	Natural logarithm of Total Factor Productivity
Independent variables	
Conventional FDI	Share of total sales in an industry j accounted for by foreign firms.
Competence creating FDI	Share of total sales in an industry j accounted for by foreign firms defined as competence creating subsidiaries.
Competence exploiting FDI	Share of total sales in an industry j accounted for by foreign firms defined as competence exploiting subsidiaries
Market concentration	Sum of squares of firms' turnover shares in each 2-digit industry
R&D engagement	Dummy equal to 1 if the firm has made investments in R&D and equal to 0 in another case.
Export engagement	Dummy equal to 1 if the firm has exported and equal to 0 in another case.
Size	Logarithm of employment

Definition of variables (Classification of subsidiaries)

	Variable	Definition
MNE knowledge flows	Headquarter	Dummy equal to 1 if the firm use headquarters as source of information for innovation activities and equal to 0 in another case.
	Other enterprises within the MNE group	Dummy equal to 1 if the firm use other enterprises within the MNE group as source of information for innovation activities and equal to 0 in another case
Local knowledge flows	Clients	Dummy equal to 1 if the firm use clients as source of information for innovation activities and equal to 0 in another case
	Suppliers	Dummy equal to 1 if the firm use suppliers as source of information for innovation activities and equal to 0 in another case
	Competitors	Dummy equal to 1 if the firm use competitors as source of information for innovation activities and equal to 0 in another case
	R&D organizations	Dummy equal to 1 if the firm use R&D organizations (e.g. universities and R&D centers) as source of information for innovation activities and equal to 0 in another case

Appendix 4.2

Descriptive statistics and pairwise correlations

	1.	2.	3.	4.	5.	6.	7.
1.Total Factor Productivity (TFP)	1.00						
2.Market concentration	0.06	1.00					
3.Export engagement	0.35	0.00	1.00				
4.R&D engagement	0.19	-0.02	0.13	1.00			
5.Size (Log employment)	0.78	0.06	0.38	0.19	1.00		
6.Competence creating FDI	0.13	0.01	-0.01	0.08	0.08	1.00	
7.Competence exploiting FDI	-0.01	0.06	0.05	0.05	-0.01	0.10	1.00
Mean	10.9	-4.4	0.2	0.1	3.3	-2.8	-2.1
SD.	1.4	1.9	0.4	0.2	1.2	1.1	0.6

Source: Own calculation based on EDIT IV and EAM (DANE)

CHAPTER V. ABSORPTIVE CAPACITY, SPILLOVERS AND REGIONAL DISPARITIES IN COLOMBIA

5.1 Introduction

Colombia has been becoming a dynamic growing economy in the Latin American region and it is notable its potential as a succeeding recipient of MNE. A set of notable improvements taken place in the country, has positively changed the institutional landscape as a FDI recipient economy: Colombia is, in fact, among the top five recipient countries in the Latin American region; the inflows has shown a positive trend in last years although declined in 2015 driven by falling flows in the petroleum sector and in mining (UNCTAD, 2016). However, it is not yet seen as a favorable scenario to be considered not a succeeding case regarding the formation of innovative clusters in manufacturing activities as they exist, for instance, in other distant locations within other emerging economies such as the Beijing ITC cluster or the Bangalore case in India (Xin, 2003; Manning, 2008; Hill and Mudambi, 2010; Lorenzen & Mudambi, 2013). Since the generation of spillovers may be seen as a favorable engine for the formation of clusters, new evidence about the effects of inward FDI in geographical spaces of developing contexts is needed. This would encourage new contributions in both theoretical and empirical sides that would contribute to build and improve the set of explanations about the existence of differentiated effects across geographies and the existence of international differences in these local-based processes.

In the tradition of economics and business literature, key research evidence on spillovers have been focused on the positive productivity effects that FDI inflows generated in home territories. The basic foundations were established, on the one hand, due to the presence of ownership advantages in multinational enterprises (MNE), among which technological superiority and productivity differentials are found (Blomström & Kokko, 1998; Crespo & Fontoura, 2007) as well as to the semi-public characteristic of technological knowledge that avoid the complete appropriation of R&D results (Griliches, 1979). Since the pioneering models, a spatial perspective has been present, being justified on the geographical concentration of advanced economic activities that favor the emergence of innovative clusters (Audretsch & Feldman, 1996).

On the other hand, the ability of the domestic sector to assimilate foreign technologies and the potential agglomeration externalities, has been seen as key determinant factors (Porter, 1986, 1990; Blomstrom & Kokko, 1996; Driffield, 2001; Driffield & Love, 2007). So far, the large amount of empirical evidence on the issue argue about the importance of a mismatch of characteristics that are defined at both firms and territories levels, recalling that the possession of location advantages also become a relevant argument for the spillovers' explanation (Markusen & Venables, 1999; Blomstrom et al. 2001). In this sense, the superior

technological capabilities of foreign subsidiaries may induce domestic firms to make greater efforts on innovation to avoiding the risk of crowding out (Castellani & Zanfei, 2007; Criscuolo et al., 2010). However, it also depends on the type of activities carried out by subsidiaries and whether they are competence-creating units (Cantwell & Mudambi, 2005; Santangelo, 2012; Álvarez & Cantwell, 2011; Albis & Álvarez, 2014).

Academic analysis for both developed and developing countries shape a broad set of available empirical evidence. Pioneering contributions were developed to measure horizontal or intra-industry spillovers at the industrial level in Venezuela (Aitken and Harrison, 1999), Mexico (Blomstrom & Persson, 1983; Blomstrom & Wolf, 1994), Indonesia (Blomstrom & Sjoholm, 1999) and Morocco (Hadan & Harrison, 1993). The availability of firms' level data improved notably the state of knowledge in this field of research. Also, modeling and methodological advances have taken place and the evidence has notably increased. Moreover, important growing attention has been paid to the vertical spillovers approach assuming that inter-industry relationships may induce positive effects and a better knowledge of them could derived into pertinent implications for industrial and innovation policies (Javorcik, 2004; Havranek & Irsova, 2011; Behera, 2015). Nonetheless, there are still controversial aspects and findings that not always go in the same direction (Meyer, 2011).

At this point, it has sense to combining firm' level analysis and geographies together as complementary categories in the spillovers research' framework. On the one hand, the availability of micro data is a key factor for research on spillover because it permits to capture and to analyze heterogeneity. On the other, most of the contributions take the national context as the geographical reference while agglomeration and clustering are both local-based processes. These reasons justify for claiming, also according to the background, more research at the subnational level of analysis, even more important once country size is large and once administrative decentralization prevails. Colombia has been traditionally centralized but a decentralization process started after Constitution Signature in 1991. In the country, there are a clear division of economic regions although they still enjoy a moderate level of administrative autonomy.

Evidence about regional spillovers show that the existence of these effects is confined to non-assisted area regions of the UK: Productivity spillovers do not necessarily occur in regions where significant inward investment incentives are available (Driffield, 2004). On the other hand, the study of innovative regions made by Zhou and Xin (2003) confirms the generation of interactive patterns between MNE and local technology actors in China's leading information communication technology (ICT) service cluster in Zhongguancun, Beijing. Their findings reveal that the relationship between MNEs and local firms is hierarchical, but also interdependent and evolutionary since local firms can learn more due to the presence of other related enterprises and R&D facilities.

The co-evolution of firms and locations is also an aspect that deserves more research in peripheral areas and developing contexts. The estimation of spillovers in China using

manufacturing census data for the period 2000–2003 reveal significant positive effects for the productivity of domestic firms in the same industry, but these spillovers are likely to be confined to regions; that is, domestic firms benefit more from the presence of foreign firms in the same sector and in the same region (Xu and Sheng, 2012). On the other hand, drawing into the relevance of peripheral areas in Europe, Santangelo (2012) argues about the association between the local embeddedness of subsidiaries and their competence-creating entry motives. Some additional arguments about the relationship between organization, technologies and geographies, are those related to the increasing disaggregation of the global value chain activities; this fact claims for the division between specialized and standardized ones, and also for the orchestrating and specialization roles of firms, underlying the relevance of knowledge connectivity (Cano-Kollman et al, 2016).

In this paper, we provide a conceptual framework for the explanation of conditional factors that could explain the generation (or absence) of spillovers across regions (provinces) in Colombia; this is empirically tested using firm level panel data for manufacturing industries in the period 2003-2012. We argue that spillovers at the subnational level of analysis require the joint consideration of regional heterogeneity, industrial specialization and firms' embededdedness in the same framework. The line of thought about the difficulties for clustering possibilities is developed here across different provinces in the country, as follows: Regional heterogeneity is defined by industry specialization as a determinant of the opportunities for structural change "oriented to" and "driven by" innovation, this combined with firms' embededdedness and their international connections as determinant aspects.

Next section presents the theory and hypothesis development. The third section is devoted to data description. Section fourth contains the empirical model and the estimation outputs. Section fifth discusses the results, and the sixth presents some concluding remarks and implications.

5.2 Theory and hypothesis development

Literature background provides us supportive arguments for the explanation of spillovers effects in developing contexts, and the differences across regions (provinces) within the same country. The traditional interplay defined by ownership (O) and location (L) advantages acquires special connotations for the subnational level of analysis, and it contributes to the definition of a set of possible outcomes regarding the existence of positive spillovers (Meyer et al., 2011). The general assumption of technological superiority of foreign firms is still valid while it is argued that domestic absorptive capacities become a very relevant aspect (Narula & Marin, 2003; Girma, 2005; Álvarez & Molero, 2005). Regarding the potential sources of spillovers, imitation and demonstration effects make more likely the possible generation of positive effects from FDI (Castellani & Zanfei, 2007; Criscuolo et al., 2010) while modern and advanced facilities in a particular location –such as scientific and technological ones- are accepted to be enhancing factors for the generation of them (Cantwell & Piscitello, 2002; 2005).

In the IB literature, it is broadly argued that one of the significant aspects explaining spillovers is the type of activities that are performed by firms in foreign contexts; particularly, whether activities related to the generation of knowledge, are carried out or not in the host territory –i.e. R&D activities. This connects with the argument of competence creation versus exploitation mandates or their acquisition through time at the subsidiary level (Birkinshaw, 1996; Cantwell & Mudambi, 2005; Ciabuschi et al. 2011). The issue is that R&D activities and innovation are more related to exploration mandates of creative subsidiaries while exploitation competencies are suitable to those activities oriented to local adaptation (Nobel and Birkinshaw, 1998; Kuemmerle, 1999). Moreover, some aspects of the market structure such as the competition and internationalization levels, as well as the industrial specialization can also be understood as determinant elements to explain spillovers across regions (Santangelo, 2012; Giuliani et al. 2014).

Regarding location, those territories with higher scientific and technological capabilities that likely enjoy better conditions for entrepreneurship, are better endowed than others to favor innovation dynamics and learning (Cantwell & Santangelo, 2002; Cantwell & Piscitello, 2005). A more advanced local system of innovation is also more favorable for the development of connections between foreign and domestic firms, because it is more likely that both collaboration and competition relationships would be more balanced among the different units. Overall, the level of absorptive capacities in host locations is a determinant factor of the potential positive spillovers, an impact that can be explored at both firm and business sector levels (Álvarez et al, 2015; Girma, 2005).

These antecedents reveal the importance of advantages in a particular local setting. Based on the co-evolution of firms and territories, the idea is that institutional local capabilities may become a conditional factor for the level of local embeddedness of foreign units that would favor entrepreneurship and innovation dynamics in territories (Kumaraswamy et al., 2012; Álvarez and Marin, 2013). This is also related to the level of integration in both the local host territories as well as within the MNE, claiming for the relevance of global and local connections (Marin and Bell, 2010; Giuliani et al. 2014; Achcaoucaou et al., 2014). This interplay can be understood as a crucial combination of aspects for the generation of positive spillover effects in both developed and developing contexts. In particular, according to the literature, innovation strategies in MNE define the role of subsidiaries and how they relate (vertically) and create linkages in foreign host territories. Subsidiaries with competence-creating (CC) mandates often show a higher R&D-intensity, they are qualitatively different in their determinants of R&D – e.g., local supply potential and strategic independence matters-, while they also may enter in innovative clusters to source knowledge locally.

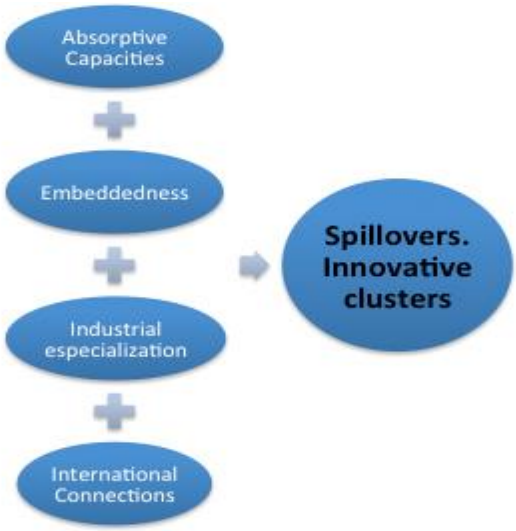
Then, our proposal is to show that the possible generation of spillovers in particular developing contexts may be conditioned first, by the different possession of advantages at both, firms and regional levels. Secondly, these advantages may be conditioned by the characteristics of industries and the business sector; in particular, taking into account the

aspects related to market structure and technological patterns. And third, the outcome would highlight the role of innovation, not only R&D that may be modulated by foreign firms' strategies and embeddedness. This later aspect makes the difference between creative or exploitative competencies, defining also the learning abilities in domestic firms that are presumable larger in those showing a higher level of international connections.

The theoretical argument presented here is that the potential for spillovers and the generation of innovative clusters in developing economies, depend on the combination of the following four dimensions: First, the level of absorptive capacities (AC), this defined not only at the firms' level but also with implications for both locations and the business sector that includes domestic and foreign firms; it is plausible to think that a higher level of advance in the local system of innovation makes more likely a higher level of embeddedness of foreign units in territories that defines relevant networks within the system. Second, the local industrial structure and specialization, assuming that the importance of innovation is greater in higher value-added activities and this is conditioned by the position in the value chain. Third, the level of international connections of the domestic business sector that would entail positive effects such as those derived from learning by exporting.

It must be clarified that Figure V. 1 shows the relevant dimensions that enter into a dynamic conception of the evolution of both firms and location. The interplay among these dimensions is supported by the coevolution of firms and location in the sense that absorptive capacities may be applied to domestic firms that together with the foreign ones shape the business sector, this conditioned by industrial structure and specialization. The evolution of location would be then determined not only by the level absorptive capacities, but also the international connections of firms –domestic and foreign- and the level of embeddedness of the later, and its dynamics.

Figure V. 1. Determinant factors of potential spillovers in developing regions

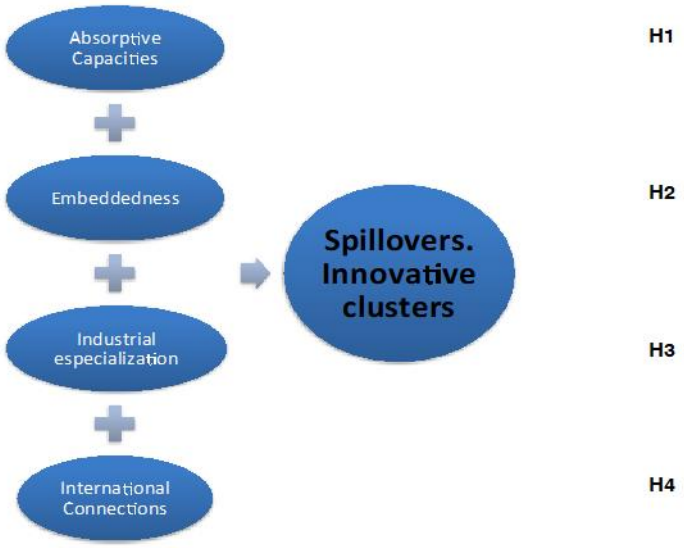


Source: the authors.

Taking this theoretical contribution into account, the hypothesis that this paper develop are the following –in Figure V. 2:

- First, the presence of more R&D and technology-intense firms is more favorable for the generation of regional spillover effects since this is a signal of higher absorptive capacities. Meanwhile, the existence of higher innovative efforts that implies other non-R&D activities may go also in favor of regional spillovers generation (H1). Moreover, in developing context, it is more likely that spillover effects take place in more technological advanced regions because this would favor a higher level of foreign embeddedness of firms as well (H2).
- Second, industrial specialization is related to the predominance of industrial sectors and a particular market structure that would generate particular micro effects. On the one hand, it is expected that more competitive (less concentrated or oligopolistic) industries make more likely the generation of spillover effects (H3).
- And third, more internationalized firms –those with higher international connections- are better prepared for the absorption of spillovers, reason why these are more likely in domestic exporting firms (H4).

Figure V. 2. Determinant factors of potential spillovers in developing regions and related hypothesis



Source: the authors.

Then, technology and markets can be seen as the key analytical categories found at the core building blocks of the relationship between FDI, geographies and spillovers. The operational variables for these analytical categories imply some technological indicators and some conventional industrial structure indicators as well. First, the amount of R&D investment

devoted by firms (R&D intensity) and the efforts made on other innovation activities can be adequate proxies for the level of firms' absorptive capacities in developing regions such as the Colombian provinces. Secondly, according to the literature, it can be expected that the local (regional) innovation capacity allow us to approach the potential embeddedness of foreign firms. Third, the level of market concentration can be quantitatively approached by the Herfindahl Index and, in addition, the type of industries can be considered according to the classification of industries derived from the consideration of their innovation patterns; that is to say R&D intensive, scale intensive, labor intensive, or resources intensive. And finally, the export engagement permits to approach other sources of learning that derive from firms' international market connections.

5.3 Data sources and descriptive analysis

5.3.1. Data sources

The statistical information used in the empirical analysis carried out in this paper is a panel data at the firm level which integrates information from two different original sources that have been collected by the National Statistics Department of Colombia (DANE)[22]. The first one is the Annual Manufacturing Survey (henceforth EAM). This survey can be considered a census of Colombian manufacturing sector and provides general economic data on firm characteristics and performance variables such as sector of activity[23], legal organization, sales, added value, employment, expenditures, fixed assets and trade (among others). The EAM includes information on the industrial establishments with ten or more employees or a production value higher than that stipulated for the year of implementation of each of the version of the survey. Then a panel data covering the period from 2003 to 2012 is being used.

The second database is the Development and Technological Innovation Industrial Survey (EDIT, for its acronym in Spanish), in their versions II to VI[24]. Following the framework of the Oslo and Bogotá Manual, the dataset collects two-year of information on innovation activities undertaken by industrial firms according to the directory of establishments in the Annual Manufacturing Survey (EAM). By merging EDIT data into the EAM Survey we added the information of variables related to the investment in innovation activities, which are gathered in the EDIT for each year[25]. From this survey, we information was gathered for annual investment in R&D and innovation activities.

After a process of cleaning the database to correct inconsistencies, missing values and errors in the available information, we obtained an unbalanced panel with 59.497 observations and

[22] The firm-level data provided by this agency are subject to a strict regulation of the statistical reserve. Hence, the data were worked directly at the DANE's offices through the signing of a specific agreement of collaboration.
[23] The survey uses the International Standard Industrial Classification (ISIC Rev. 3) adapted to Colombia by Dane.
[24] The pilot version of the survey was conducted in 1996. In this research, we use the following version of the survey: EDIT II (2003–2004), EDIT III (2005-2006), EDIT IV (2007-2008), EDIT V (2009-2010) and EDIT VI (2011-2012).
[25] The two databases have common firm identifiers, and this aspect allows us to combine them for research purposes.

8.029 domestic firms for the period 2003-2012[26]. Regarding the definition of foreign firms in our dataset, the cutting off point is delimitated by the level of 25 per cent of foreign ownership of the social capital in the firm. The set of MNE subsidiaries in the database is composed by 362 firms and 4.064 observations. Appendix 1 presents some basic descriptive statistics and the correlation matrix (see Tables A1 and A2 in the Appendix) for the main variables that will be used in the regression analysis. In general terms, there is not presence of any major problem of multicollinearity among variables.

5.3.2. The presence of foreign firms in Colombia

Colombia shows some structural systemic weaknesses that are related to the low smart industrial specialization. One characteristic aspect is the presence of a dual economy in which the industrialization process is combined with the still predominance of some basic activities in many provinces. This goes hand in hand with the distribution of foreign subsidiaries according to both industries and locations. The negative influence of the not-smart specialization in the country is related to the predominance of medium tech industries that are mostly technologically dominated by suppliers, an aspect that is also corroborated by the proportion of foreign subsidiaries in non-high tech industries.

In fact, according to data from the innovation survey in Colombia (EDIT), the distribution of foreign subsidiaries by industries show that only three industries concentrate more than 50% of foreign firms since chemicals and chemical products (20%), food beverages and tobacco (15%) and rubber, plastics and fabricated metal products (15%) are clearly predominant**.** The foreign presence in Colombian manufacturing is then dominant in medium technology intensity industries and according to Pavitt Taxonomy would be clearer in those industries dominated by suppliers (Pavitt, 1984). By contrast, foreign firms are less relevant in science-based and high-technology industries.

Another distinctive aspect is the spatial localization pattern of foreign subsidiaries in the country, t%), Valle (13%) and Antioquia (13%). The presence of foreign firms is in fact, positively related to the absorptive capacities of regions, as it can be seen in Figure V.3. To approach the absorptive capacity (AC) of regions, the share of regional R&D expenditure to total regional GDP has been taken.

Although taking into account the geographical concentration of foreign firms in few locations (mainly in Bogota area), there is also a very low relationship between the absorptive capacities (AC) of domestic and foreign firms -measured by the R&D intensity-. It can be noticed that the relative absorptive capacities between the two types of firms are unbalanced. In fact, there is a lack of relationship between the hat is highly concentrated since 80% of them are placed in just three provinces: Bogotá (50%), Valle (13%) and Antioquia (13%).

[26] In the cleaning of the database several aspects have been taken into account: (i) to exclude firms with missing or zero values in any of the main variables of interest during the observation period; (ii) data imputation using the Hot Deck method in the case of missing, zero or extreme values between two years (3) we excluded the sectors with zero or low foreign presence (ISIC 20, 23, 32, 33 and 35).

The presence of foreign firms is in fact, positively related to the absorptive capacities of regions, as it can be seen in Figure V. 3. To approach the absorptive capacity (AC) of regions, the share of regional R&D expenditure to total regional GDP has been taken.

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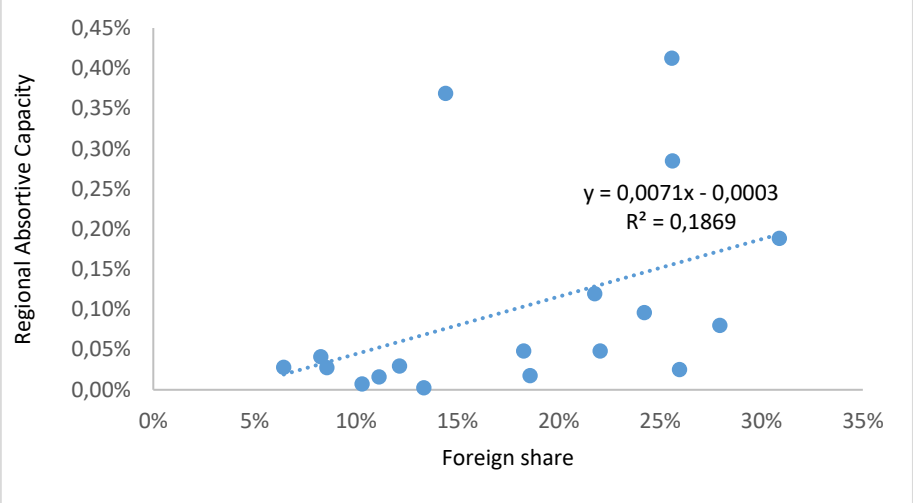
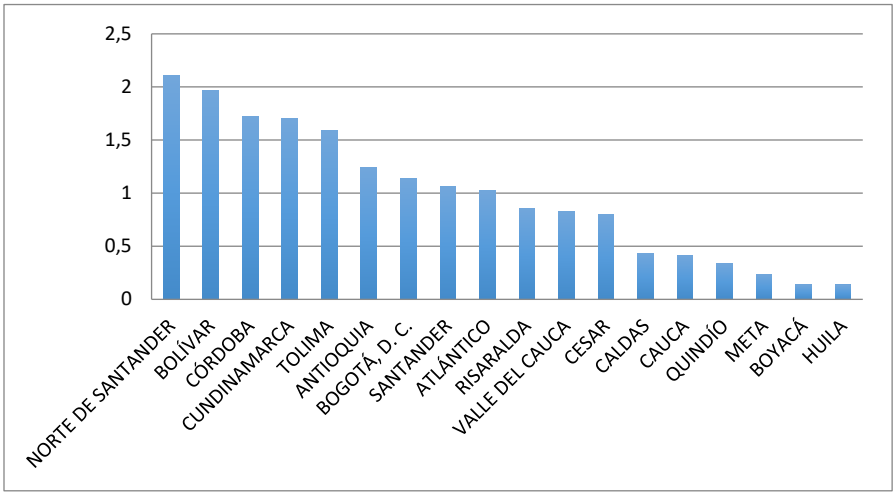
Figure V. 3. Regional absorptive capacity and foreign presence



Source: Own calculation based on EDIT IV and EAM (DANE)

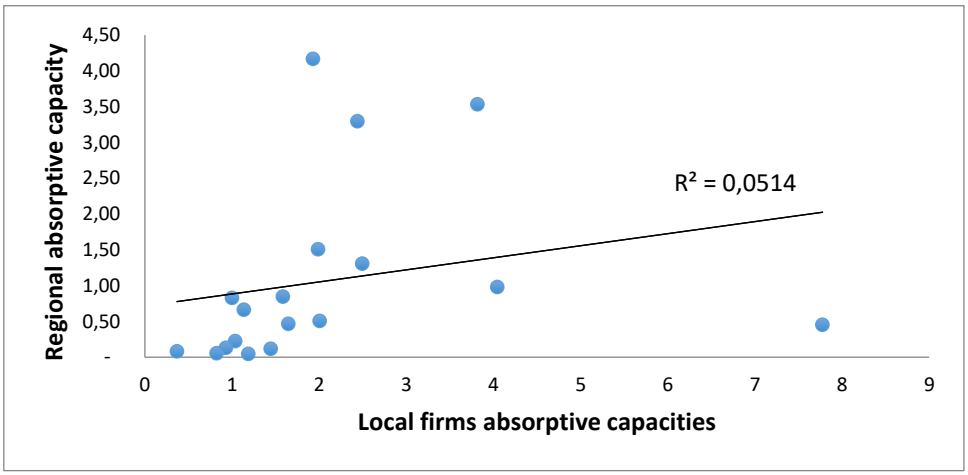
Figure V. 4. Relative absorptive capacities of firms, by provinces



Source: Own calculation based on EDIT IV and EAM (DANE)

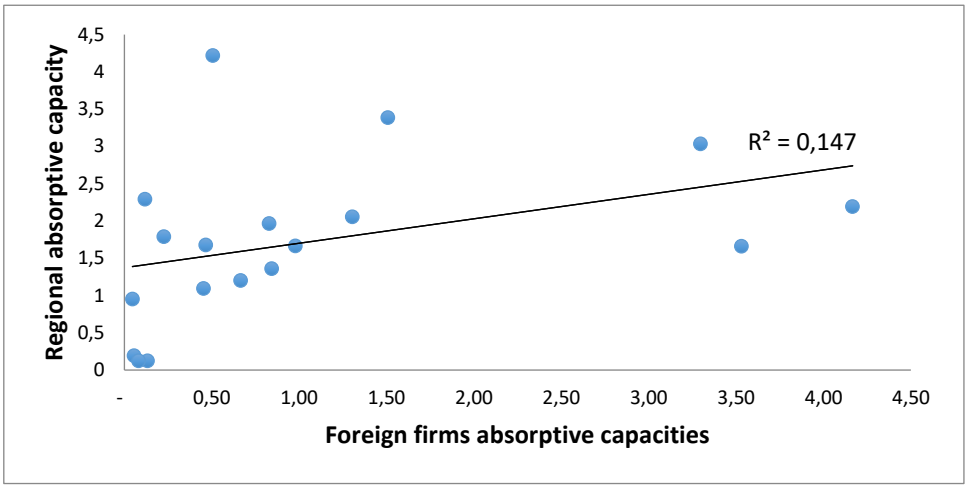
On the other hand, assuming that the potential for clusters formation is greater when there is a positive relationship between the regional AC and the absorptive capacities of firms, this is low for local firms and higher in the case of foreign subsidiaries –Figure V. 5 and Figure V. 6. This shows a better connection between foreign innovative activities and the location capacities. At the same time, this relationship would reveal that embeddedness within location could be distinguished in the case of both foreign and domestic units. In some Colombian provinces, there is a certain level of networking possibilities that would go in favor of the development of innovative entrepreneurship and potential clusters formation.

Figure V. 5. Regional AC and local firm's AC



Source: Own calculation based on EDIT IV and EAM (DANE)

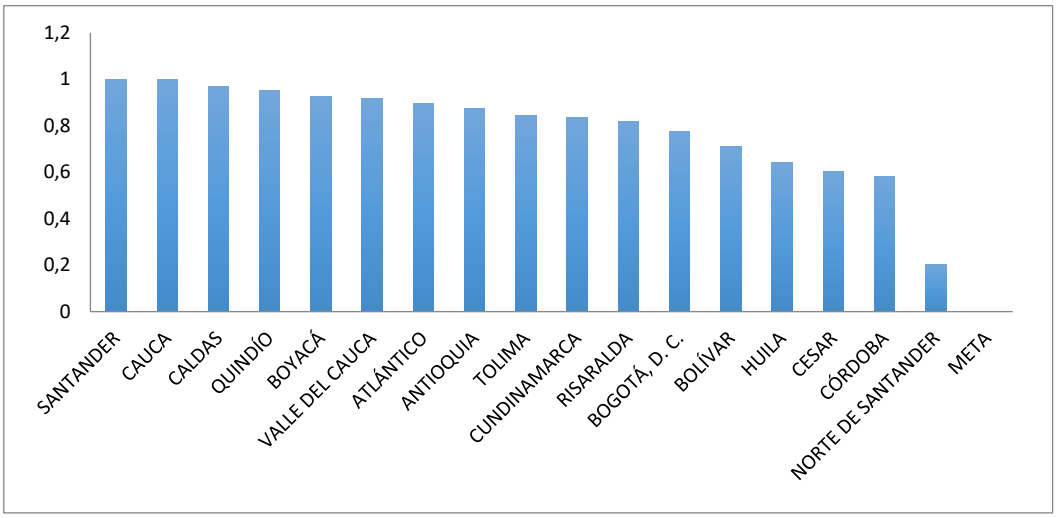
Figure V. 6. Regional AC and foreign firm's AC



Source: Own calculation based on EDIT IV and EAM (DANE)

Considering specific locations, embeddedness is very low in those places where foreign units are R&D intense such as Bogotá-Cundinamarca where there is the highest concentration of foreign firms –Figure V. 7. Embeddedness is here measured by an index of collaboration of firms with other agents of the region. Santander and Cauca are the provinces with the better level of embeddedness in comparison with the rest of provinces. In the first province, foreign and domestic are similar and the regional AC is very low; in the second, there is a higher regional AC but the relative AC between foreign and domestic firms goes in favor of the later. In Norte de Santander and Cordoba the corresponding values of this indicator are notably lower. These two provinces show an even lower regional AC and the relative AC is a weakness aspect because the superior AC of foreign firms in comparison to the domestic one. This fact justifies a low potential of cluster formation in many provinces, an aspect that becomes a conditional factor for the generation of spillover effects.

Figure V. 7. Embeddedness index of foreign firms, by provinces



Source: Own calculation based on EDIT IV and EAM (DANE)

Therefore, after this short description, there are some additional key aspects that can be related to the existence of some structural systemic weaknesses in Colombia. On the one hand, the low-smart industrial specialization and the presence of a dual economy in which industrialization is combined with basic activities, being also scarce the links between public and private sectors of the economy. Secondly, there is also an unequal distribution of AC between foreign and domestic firms in Colombian provinces, more notable in some of them, an aspect that defines geographical inequalities. Moreover, there is a disconnection of foreign innovative activities and the location and business sector capacities. While some locations show good AC, foreign firms underperformance in the knowledge generation there. Finally, although some local contexts have a high potential for clusters formation because the presence of large AC, the lack of embeddedness in some of them may be explained by the fact that competence creating subsidiaries are less active. Accordingly, there will be minor possibilities for networking and this does not favor innovative entrepreneurship.

5.4 Empirical analysis

The evaluation of regional spillovers from multinational enterprises in Colombia is conducted here in two different stages. First, we estimate total factor productivity (TFP) for the sample of domestic firms. Second, we examine the correlation between domestic firms' productivity and the presence of foreign firms at regional level.

In the first stage, the productivity of each firm is estimated using a production function approach. We assume a log-linear transformation of a Cobb-Douglas production function, of the following type:

$$y_{it} = \beta_0 + \beta_l l_{it} + \beta_k k_{it} + \beta_m m_{it} + \omega_t + \varepsilon_{it} \qquad \text{(Eq. 1)}$$

where lower-case letters in Eq. (1) refer to natural logarithms and subscripts *i* and *t* refer to firm and year, respectively. Here y_{it} represents the real output of the firm;l_{it}, k_{it} and m_{it} are inputs of labor, capital and raw materials, respectively. The term ω_{jt} represents firm-level productivity and ε_{it} is an i.i.d. component, representing unexpected deviations from the mean due to measurement error, unexpected delays or other external circumstances.

The firm's output is defined as valued added deflated by industry-specific producer price indices at the two-digit ISIC classification. We distinguish two types of labour: (1) unqualified personnel (blue-collar workers), and (2) qualified personnel, defined as the sum of professionals, technicians and sales and administrative staff (white-collar workers). The material input is defined as the consumption of raw materials deflated by materials producer price index. The stock capital is defined as the value of fixed assets at the beginning of the year deflated by the simple average of the deflators for terrains, buildings and structures, machinery and equipment, transport equipment and office equipment. Additionally, we included 15 dummy variables in the estimation to control industry effects.

To estimate TFP, we follow the semi-parametric method introduced by Levinsohn & Petrin (2004). This approach uses intermediate inputs as proxy for unobserved productivity shocks to account for the possible endogeneity resulting from the high correlation between these shocks and the levels of inputs used in the production[27].

In the second stage, we used a general model of determinants of total factor productivity of domestic firms in function to a measure of foreign investment. The model takes the following form:

$$\ln TFP_{it}^{d} = \alpha_0 + \alpha_1 RFDI_{jrt} + \boldsymbol{\alpha_2 X_{it}} + \mu_t + \varepsilon_{it} \qquad \text{(Eq. 2)}$$

Where the subscripts *i, j, r* and *t* in Eq. (2) refer to firm, sector, region and year, respectively. The variable $\ln TFP_{ijt}^{d}$ is the logarithm of domestic firms' productivity; $\mathrm{RFDI_{jrt}}$ captures the extent of foreign presence in sector *j*, region *r* and time *t* and X_{ijt} is a vector of relevant control variables. Whereas parameter α_1 captures the effect of spillovers from foreign firms, μ_t denotes unobservable time-invariant firm-specific effects and $\varepsilon_{\mathrm{it}}$ the error term.

We use affiliate added valued as a measure of MNE presence in six sub-regions (provinces) of Colombia. The sub-regions were selected according geographical and economic proximity of the departments that shape the administrative structure of Colombia. It also takes into account the concentration of foreign investment between territories.

Moreover, the following control variables were included in the vector $\boldsymbol{X}$: (1) the Herfindahl index, calculated as the sum of squares of firms' turnover shares in each 2-digit industry; (2) the export engagement of domestic firms, is a dummy equal to 1 if the firm has exported and equal to 0 in another case; (3) the knowledge absorptive capacity of domestic firms, measured as the relative position of a firm's innovation effort (innovation investment for employee) in relation to the maximum value in the industry *j* (4) the innovation regional capacity, that is defined as the share of regional innovation activities expenditure to regional GDP and (5) a four sector classification which includes sectors intensives in R&D, scale, labour and natural resources (Guerrieri, 1992)[28]. The detailed definition of variables can be found in Appendix 5.1. The results of the panel data estimations can be found in Table 2.

Regional spillovers in Colombia are significant and positively related with the presence of absorptive capacities (AC) in domestic firms. AC at the firm level is here defined as the firms' innovation efforts measured in relative terms as the distance to the frontier. These effects adopt also relevance considering location since the coefficient of the innovation capacity of provinces got a positive and significant sign. It is more likely that these effects take place in those traditional industries – with regard to natural resources intensive activities- while they are not significant in the more technological advanced industries (R&D intensive

[27]To estimate total productivity, we use the Stata routine *levpet* developed by Petrin et al. (2004). The results of this estimation are not included here, but are available upon request.
[28]The classification of Guerrieri (1992) it is an adaptation of sectorial Pavitt taxonomy (1984).

ones). Meanwhile, the negative sign revealed in the scale intensive sector can be observed according to the possible obsolescence level of plants in this type of industries that conduit to negative impacts on productivity results regarding their foreign competitors. A positive relationship is found with the export propensity of firms, something that is expected according to previous evidence that shows how innovation performance of foreign firms and exporting domestic ones is more similar. However, industrial concentration is not a significant aspect.

5.5 Discussion of results

The results of the empirical model estimations reveal that although conventional spillovers are not significant in Colombia as it was expected, the regional dimension provides new insights (Table V. 1). According to our findings, the level of firms' absorptive capacities is a determinant factor for the generation of regional spillover effects in manufacturing firms in Colombia. Hypothesis 1 (H1) is then confirmed. Generally speaking, being aware that R&D investment is not very large in developing context, other efforts addressed to improve innovation by firms should be taken into account because they also shape the firms' absorptive capacities that would favor spillover effects. These results come to justify that innovation activity is an adequate indicator for measuring firms' AC in developing economies.

On the other hand, the innovation regional capacity (IRC) is a relevant aspect explaining the generation of spillovers as well. This implies that a higher likelihood of embeddedness can be considered as a driver of spillovers also in developing contexts such as Colombia. Therefore, H2 is satisfactory confirmed. Although the relative AC of foreign and domestic firms was not favorable from the descriptive analysis, model estimations show a significant and positive sign of the IRC coefficient that informs us about the importance of foreign subsidiaries' strategies also for the generation of regional spillovers, this in line with previous evidence (Santangelo, 2012). Regarding the type of competencies that foreign subsidiaries may have and whether these are more creative since they likely would require higher levels of networking within the local host territory.

Regarding industrial specialization, the results obtained from the estimations of the empirical model are mixed. On the one hand, market structure does not seem to be a determinant aspect for the generation of regional spillovers. Although it was expected that less concentrated – more competitive- markets would derive on positive effects for domestic firms, the estimations results do not permit to set this affirmation since the corresponding coefficient is not significant. On the other hand, spillover effects are related to the fact that business sector is specialized in some types of industries and then, this is confirmed as a determinant aspect. The controls for industries are significant in all the case against natural resources industries. This implies the case of R&D intensive industries, scale intensive sectors and labor intensive ones. Nonetheless, according to the value of the estimated coefficients, regional spillover effects are larger in those industries that are labor-intensive (in comparison to those natural

resources intensive) followed by R&D intensive and scale intensive industries. So far, although this finding does not imply any kind of industrial determinism argument, it confirms at least the prevalence of a more traditional innovative industrial pattern. These results do not allow us to accept the validity of H3.

Table V. 1. Estimation results

Dependent variable: TFP (log)	**Conventional spillover model**	**Regional spillover model**				
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Herfindahl index	-0,092	-0,092	-0,085	-0,084	-0,085	-0,084
	(0,109)	(0,109)	(0,109)	(0,109)	(0,109)	(0,109)
Export engagement	0.309***	0.309***	0.309***	0.309***	0.309***	0.309***
	(0,034)	(0,034)	(0,034)	(0,034)	(0,034)	(0,034)
Firm absorptive capacity	0.665***	0.666***	0.673***	0.673***	0.673***	0.673***
	(0,063)	(0,063)	(0,063)	(0,063)	(0,063)	(0,063)
Conventional spillovers		0,001				
		(0,002)				
Regional spillovers			0.003***	0.003***	0.003***	0.003***
			(0,001)	(0,001)	(0,001)	(0,001)
Regional absorptive capacity (IA)	0.106***	0.106***	0.093***		0.093***	
	(0,020)	(0,020)	(0,020)		(0,020)	
Regional absorptive capacity (R&D)				0.258***		0.258***
				(0,050)		(0,050)
Size	0.826***	0.826***	0.826***	0.826***	0.826***	0.826***
	(0,008)	(0,008)	(0,008)	(0,008)	(0,008)	(0,008)
R&D intensive sector	0.165***	0.165***	0.155***	0.156***	0.057**	0.057**
	(0,018)	(0,018)	(0,018)	(0,018)	(0,028)	(0,028)
Scale intensive sector	0.110***	0.110***	0.098***	0.100***		
	(0,026)	(0,026)	(0,026)	(0,026)		
Labor intensive sector	0.401***	0.401***	0.386***	0.389***	0.288***	0.289***
	(0,020)	(0,020)	(0,020)	(0,020)	(0,028)	(0,028)
Natural resource intensive sector					-0.098***	-0.100***
					(0,026)	(0,026)
Constant	Yes	Yes	Yes	Yes	Yes	Yes
Observations	67,979	67,979	67,979	67,979	67,979	67,979
Firms	9,826	9,826	9,826	9,826	9,826	9,826
Method	Random effects	Random effects	Random effects	Random effects	Random effects	Random effects

Note: Standard errors in brackets. * p<0.1, ** p<0.05, *** p<0.01.

Lastly, learning by exporting is a powerful argument to understand the potential for spillovers at the level of the business sector in developing economies (Girma et al., 2008; Álvarez and Cantwell, 2011). This is an aspect also confirmed in the case of Colombian manufacturing firms and therefore, H4 can be confirmed. Accordingly, this result is related to the importance of international connections for the generation of firms' capacities that deals positive spillovers effects.

5.6 Concluding remarks

Some concluding remarks derived from the empirical analysis performed in this paper allow us to state that in the case of Colombia, the evidence about absent conventional spillover is behind the general low level of clustering. This is not necessary due to the lack of manpower qualification and education in the country, since according to WEF (2016) these are not among the weak pillars of the Colombian competitiveness position and even the level of innovation does not show a problematic factor for doing business.

The contribution of this paper relies on an integrative framework built over the relationship between FDI, geographical spaces and potential spillovers that would favor the generation of innovative local clusters. The argument is that the consideration of local absorptive capacities that emerge from the combination of domestic firms, business sector and a particular industrial structure that simultaneously make more likely to get a higher level of foreign firms' embeddedness, would favor more dynamic learning processes and the potential clustering effects based on geographical proximity.

The key question that has is dealt here is related to the prevalence of a dual economy and the inexistence or lack of conditions and capabilities for the generation of spillovers in specific geographic areas or provinces. Local heterogeneity and absorptive capacities at the firm level and also at the business sector level would arise as crucial determinant factors to be taken into account to understand local spillovers. The generation of spillovers effects in the manufacturing sector clearly shows the existence of a geographical pattern that highlights the relevance of the regional innovation capacity for the generation of smart clusters.

The implications that can be derived from these findings are more related to the capability building process at the local (regional) level and in different fields of action. On the one hand, at the level of high education as a way to generate more qualified and specialized manpower in technical, scientific and engineering domains. Another field of action is related to infrastructures investment –basic and advanced-, this understood as a key asset with potential positive effects for the development of territories. A third field of action is related to the improvement of the institutional framework, in terms of market rules, property rights, and transparency that would guarantee a stable environment for businesses and technological development. Finally, another field to be taken into account is related to the generation of the favorable conditions for taking off mainly based on structural change and actions to enhance a higher level of firms' internationalization via foreign trade.

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Appendix 5.1

Variables definition

Variable	Definition
Herfindahl index	Sum of squares of firms' turnover shares in each 2-digit industry
Export engagement	Share of a firm's export value to its sales
Firms Absorptive capacity (R&D)	Relative position of a firm's R&D effort in relation to the maximum value in the industry j
Conventional spillovers	Share of total sales in an industry j accounted for by foreign firms
Regional spillovers	Share of total sales in an industry j within the region r accounted for by foreign firms, r = 1, . . ., R, with R = 6
Regional Absorptive capacity (IA)	Share of regional innovation activities expenditure to total regional GDP
Regional Absorptive capacity (R&D)	Share of regional R&D expenditure to total regional GDP
Size	Number of employees
R&D intensive sector	Knowledge intensity (R&D/Sales) in R&D intensive sectors*
Scale intensive sector	Knowledge intensity (R&D/Sales) in scale intensive sectors*
Labor intensive sector	Knowledge intensity (R&D/Sales) in labor intensive sector*
Natural resource intensive sector	Knowledge intensity (R&D/Sales) in natural resources intensive sector*

Appendix 5.2

Descriptive statistics

Variables	Mean	SD	Min	Max
Mutifactorial productivity (log)	10,89	1,41	1,89	18,49
Regional spilllovers	0,21	0,17	0,05	0,33
Export engagement	0,05	0,16	0,00	1,00
Firms absorptive capacity	0,02	0,08	0,00	1,00
Herfindahl index	0,04	0,07	0,00	1,00
Innovation regional capacity	0,02	0,08	0,00	1,00
R&D intensive sector (investment intensity)	0,04	0,07	0,00	0,30
Escale intensive sector (investment intensity)	0,02	0,07	0,00	0,37
Labor intensive sector (investment intensity)	0,05	0,09	0,00	0,29
Natural resource intensive sector (investment intensity)	0,02	0,04	0,00	0,13

Source: Own calculation based on EDIT IV and EAM (DANE)

Appendix 5.3

Correlation Matrix

	Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
(1)	TPF (Log)	1,00											
(2)	Herfindahl index	0,0492	1,00										
(3)	Export engagement	0,1973	0,03	1,00									
(4)	R&D intensive sector	-0,0155	-0,02	-0,01	1,00								
(5)	Scale intensive sector	0,018	0,09	-0,01	-0,22	1,00							
(6)	Labor intensive sector	0,1522	0,08	-0,06	-0,36	-0,21	1,00						
(7)	Natural resource intensive sector	-0,1364	-0,11	0,07	-0,46	-0,26	-0,44	1,00					
(8)	Regional Absorptive capacity (R&D)	-0,018	0,00	-0,01	0,07	0,05	-0,20	0,09	1,00				
(9)	Labor	0,7824	0,05	0,21	-0,03	0,02	0,07	-0,05	-0,03	1,00			
(10)	Firms Absorptive capacity (R&D)	-0,4656	0,04	-0,11	0,10	0,01	-0,04	-0,07	0,01	-0,65	1,00		
(11)	Conventional spillover	0,0394	0,0134	-0,022	0,1551	0,1197	-0,0042	-0,2185	-0,0309	0,0293	-0,0642	1,00	
(12)	Regional spillover	0,071	-0,0189	-0,0183	0,0733	0,0663	0,1139	-0,2154	0,2545	0,0321	-0,0561	0,2057	1,00

Source: Own calculation based on EDIT IV and EAM (DANE)

CHAPTER VI: CONCLUSIONS AND POLICY IMPLICATIONS

6.1 Conclusions

This PhD thesis tries to contribute to the analysis of technology internationalization, through foreign direct investment (FDI), and their effects on the competitive and innovation capacities of host countries, paying special attention to developing contexts. In particular, the objective has been to study the effects of FDI on the host technological capabilities through a better understanding of the technological strategies of foreign subsidiaries in the Colombian manufacturing industry. The main conclusions presented below have been structured according to the different analysis integrated in this thesis document.

The first issue addressed in this study was the existence of differences on the innovation performance of foreign subsidiaries compared to their domestic counterparts. The conclusions are as follow:

- Foreign subsidiaries show a superior technological performance than local firms in Colombia. This permits to affirm that the former can be considered as a potential source of knowledge able to generate positive spillover effects.
- Foreign firms use comparatively greater internal and external knowledge inputs to innovate. At the internal level, activities that require intermediate or basic technological capacities predominate, while those knowledge flows within the multinational groups are important as the external side; also, the flow of knowledge taking place with domestic organizations (clients and suppliers, and, to a lesser degree, universities and research centers).
- One result to highlight is that in contrast to prior evidence about the relationship between internationalization and innovation in more developed countries (Castellani & Zanfei, 2007; Criscuolo et al., 2010; Wagner, 2006), subsidiaries of multinational firms in Colombia have a similar innovation performance that national firms connected to international markets, i.e. the technology gap of foreign and exporting domestic firms is not so large.

The second relevant contribution is related to the connection between foreign subsidiaries and internal knowledge sources (with both the parent company and other subsidiaries), as well as with external sources (customers, suppliers, competitors and universities) that have a positive effect over the innovation performance of subsidiaries and over the possibility to evolve toward a creative mandate even in a developing context such as Colombia in the field of science, technology and innovation. Nonetheless, the external linkages seem to be more important to explain the presence of superior innovation capabilities. Even more, internal and

external linkages are complementary aspects. Absorptive capacities become a key aspect to increase the likelihood of making use of both internal and external linkages.

Many spillovers models assume that foreign subsidiaries are homogenous organizations. A third contribution of this dissertation is to demonstrate the relevance of considering whether foreign subsidiaries have merely exploitative mandates in Colombia or by contrast, creative units are able to generate differentiated spillover effects. In this sense, a methodological effort has been done to characterize creative subsidiaries and the econometric model allow us to satisfactory testing the hypothesis of heterogenous foreign subsidiaries.

Finally, a fourth element of novelty in this thesis is coming from the integration of space in the analysis of spillovers. Regional disparities are included in the analysis of the Colombian manufacturing industry and the results permit to demonstrate why technologically active clusters generated over the basis of foreign subsidiaries are not likely in this country. The difference between absorptive capacities at both regional and firm level, together with the role of industrial specialization, the level of embeddedness and the international connections are key elements to understand spillovers at industry and spatial levels.

6.2 Policy implications

Based on our findings, some policy recommendations to improve FDI and innovation policies can be formulated. It is recognized that each individual country would require a different mix of policies depending on its technological and institutional profile (Narula & Guimón, 2009). Also in the case of Colombian economy, some policy direction can be followed.

First, public action must recognize that FDI is a heterogenous phenomenon and because of this, selective FDI and innovation policies are required. Policy makers in many developing economies spend substantial resources in attracting inward investments, under the generalized assumption that FDI inflows will provide productivity and knowledge spillovers from more productive MNE in comparison to local firms. However, as it has been showed in the different stages of this research, not all foreign subsidiaries generate per se the same spillover effects in favor of domestic firms. Hence, public policy must pay more attention to the characteristics of FDI and their strategic motivations to improve the effectiveness of public support and then to achieve specific development objectives.

Second, due to the structural weaknesses of the Colombian innovation system, with little capacity to attract foreign investment projects intensive in R&D, it would be more appropriate for public policy to concentrate their efforts on the incremental upgrading of existing subsidiaries towards demand-driven R&D, rather than on attracting greenfield investments in supply-driven R&D (Cantwell & Molero, 2003; Narula & Guimón, 2009). Assuming the dynamics of foreign subsidiaries that may also evolve toward more creative strategies in the host locations, even in less develop economies, it is also plausible to think in policy actions oriented to more pro-innovation environment for foreign units.

Third, in the same vein, it can be useful to concentrate the public action toward policies that stimulate the interaction between foreign subsidiaries and local organization, favoring knowledge sharing; for example, through public funding of R&D projects in which foreign subsidiaries will cooperate with domestic firms, universities or research centers. This type of policies are important due to the fact that local organizations could gain access to MNE knowledge through linkages with foreign subsidiaries, and this in turn strengthens the knowledge base of the host economy and its competitiveness (Bresciani & Ferraris, 2016). In developing countries as Colombia, these policies will be successful if at the same time policy promotes the development of the scientific and technological base of host countries, for example thorough the development of critical human resources and the upgrading of the scientific system. Also, this policy must be accompanied by mechanism that would guarantee the raise of absorptive capacities in domestic firms.

Finally, it is necessary to define an agenda that create more connections and a higher level of coordination between investment promotion policies and innovation policies, which are two policy areas that have traditionally has been operated in an independent way also in the Colombian case. Historically, the Colombian FDI promotion instruments have been supported by horizontal policies, these concentrated more on the amount of inward FDI attracted than on the FDI quality and the potential to generate knowledge spillovers. The link between innovation policy and FDI promotion has been practically absent.

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CAPITULO VI: CONCLUSIONES E IMPLICACIONES DE POLITICA

6.1 Conclusiones

La presente tesis doctoral busca contribuir al análisis de los procesos de internacionalización de la tecnología, a través de Inversión Extranjera Directa (IED), y su efecto sobre las capacidades competitivas y de innovación de los países receptores, en especial los de menor desarrollo. En particular, su objetivo consistió en estudiar el efecto de la IED sobre las capacidades tecnológicas de las empresas colombianas en el sector manufacturero, a través de una mejor comprensión de las estrategias tecnológicas de las subsidiarias extranjeras que se localizan en ese país.

El primer tema tratado en la investigación consistió en analizar el desempeño innovador de las subsidiarias de empresas extranjeras en las manufacturas colombianas en comparación con sus contrapartidas nacionales. Las conclusiones que se desprenden de este estudio son las siguientes:

- Las subsidiarias extranjeras muestran un desempeño tecnológico superior al de las empresas locales en las manufacturas en Colombia, sugiriendo que este tipo de empresas puede ser consideradas como una fuente potencial de externalidades positivas de conocimiento hacia la economía local.
- Las unidades extranjeras hacen un uso relativamente más intensivo de insumos de conocimiento internos y externos para innovar. A nivel interno, predominan las actividades que requieren capacidades tecnológicas intermedias o básicas, como lo es la adquisición de tecnología incorporada y no incorporada. A nivel externo, las subsidiarias extranjeras hacen un uso más intensivo de fuentes externas de conocimiento, especialmente procedente de su grupo multinacional, otras empresas relacionadas en la cadena de producción y en menor grado universidades y centros de investigación.
- En contraste con la evidencia previa sobre la relación entre la internacionalización e innovación, especial en los países más desarrollados (Castellani y Zanfei, 2007, Criscuolo y otros, 2010, Wagner, 2006), las subsidiarias de empresas multinacionales en Colombia mantienen un desempeño innovador similar al de las empresas nacionales conectadas con los mercados internacionales.

Usando una aproximación cuantitativa, a través de modelos de datos de panel, los resultados encontrados indican que los vínculos que establecen las subsidiarias con su grupo multinacional, así como con fuentes externas de conocimiento, tienen un efecto positivo sobre el desempeño innovador de las filiales extranjeras. No obstante, los vínculos externos demuestran ser más importantes que los internos como determinante de las capacidades de

innovación de este tipo de empresas. Lo anterior sugiere que las redes de conocimiento son un factor importante para explicar la posibilidad de que las subsidiarias evolucionen hacia mayores responsabilidades creativas, incluso en un país como Colombia cuyo sistema de innovación posee un bajo desarrollo relativo en comparación a otros países más atractivos para ubicar facilidades de investigación por parte de la multinacionales. Otro hallazgo relevante es que los vínculos internos y externos son aspectos complementarios y además las capacidades de absorción de conocimiento son relevantes para explicar la posibilidad de que las subsidiarias extranjeras se encuentran conectadas a fuentes internas y externas de conocimiento.

La mayor parte de los modelos que evalúan las externalidades de conocimiento a través de la IED asumen que las filiales extranjeras son organizaciones con un comportamiento innovador homogéneo. Una tercera contribución de esta disertación consistió en demostrar la relevancia de considerar la heterogeneidad tecnológica de las subsidiarias extranjeras para explicar la posibilidad de que existan efectos de desbordamiento de conocimiento de la IED hacia la economía local. En particular, los resultados empíricos confirman que las subsidiarias con mayores responsabilidades creativas son las que tienen mayor probabilidad de generar externalidades positivas hacia las empresas domésticas de la industria colombiana.

Por último, un cuarto elemento de novedad en esta tesis es la consideración de la geografía en la explicación de los efectos de desbordamiento de conocimiento de la IED hacia la economía receptora. Una vez se incluye en el análisis las disparidades regionales, los resultados permiten demostrar la baja probabilidad de que en un país de como Colombia se desarrollen clústeres tecnológicamente activos generados sobre la base de las actividades tecnológicas y productivas de las subsidiarias extranjeras. En particular, para comprender las posibles externalidades de la IED a nivel industrial y espacial requiere considerar aspectos como las diferencias en las capacidades de absorción de conocimiento a nivel regional y empresarial, el papel de la especialización industrial de las regiones y el desarrollo de vínculos nivel local y global para generar conocimiento.

6.2 Implicaciones de política

Sobre la base de los hallazgos obtenidos es posible formular algunas recomendaciones para mejorar la política pública de fomento a la inversión extranjera, así como de innovación en Colombia. Todo ello bajo la premisa de que cada país mantiene características especiales que requieren una mezcla diferente de políticas dependiendo de su perfil tecnológico e institucional (Narula & Guimón, 2009).

En primer lugar, la acción pública debe reconocer que la inversión extranjera es un fenómeno heterogéneo y, por ello, se requieren políticas selectivas fomentar su atracción y progreso tecnológico y productivo. En muchas economías en desarrollo, los responsables de la formulación de políticas gastan recursos sustanciales en la atracción de inversión foránea, bajo el argumento que las empresas multinacionales son más productivas y tecnológicamente

más desarrolladas que las empresas locales. Sin embargo, como se ha demostrado en las diferentes etapas de esta investigación, no todas las filiales extranjeras generan *per se* los mismos efectos en favor de las empresas nacionales. Por lo tanto, la política pública debe prestar más atención a las características de la IED y sus motivaciones estratégicas, especial en materia de innovación, con el fin de mejorar la eficacia del apoyo público y lograr objetivos específicos de desarrollo.

En segundo lugar, debido a las debilidades estructurales del sistema de innovación colombiano, caracterizado por su baja capacidad de atraer proyectos de inversión extranjera intensivos en investigación y desarrollo, sería más apropiado que las políticas públicas concentraran sus esfuerzos en promover el desarrollo de capacidades de innovación en las subsidiarias extranjeras que ya existen en el país en lugar de atraer nuevas inversiones (Cantwell & Molero, 2003; Narula & Guimón, 2009). Este tipo de intervención parte de considerar que, incluso en economías en desarrollo, con el tiempo las unidades extranjeras pueden evolucionar hacia responsabilidades más creativas dentro de su grupo multinacional.

Un tercer elemento a considerar, es la necesidad de promocionar el intercambio de conocimiento a través de la interacción entre las empresas extranjeras y las organizaciones locales. Por ejemplo, a través de la financiación pública de proyectos de investigación en los que las filiales extranjeras cooperen con empresas nacionales, universidades o centros de investigación. Este tipo de políticas permitirían que las organizaciones locales tengan mayor acceso a los conocimientos generados por fuera del sistema de innovación y así reforzar la base de conocimiento y la competitividad de la economía receptora (Bresciani & Ferraris, 2016). Esto requiere que a su vez se implementen acciones de política orientadas a consolidar un ecosistema más favorable a la innovación, por ejemplo, a través de una mayor cualificación del recurso humano, el fortalecimiento del sistema científico y tecnológico local y el fomento de la capacidad de absorción de conocimiento de las empresas nacionales.

Finalmente, es necesario definir una agenda que genere un mayor nivel de coordinación entre las políticas de promoción de la inversión extranjera y las políticas de innovación; áreas que tradicionalmente han operado de manera independiente también en el caso colombiano. Así mismo, es necesario aplicar políticas que consideren la calidad y potencial de la inversión extranjera para generar externalidades de conocimiento positivas como elementos centrales para diseñar políticas públicas de atracción y fomento de inversión extranjera.

6.3 Referencias

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APPENDIX

Appendix 1. Database construction

This appendix explains the construction of the quantitative data used in the PHD thesis. To perform the study, two main datasets were used: The Annual Manufacturing Survey (EAM) and the Development and Technological Innovation Industrial Survey (EDIT). Both collected by the National Statistics Department of Colombia (DANE).

The first one is a survey that can be considered a census of the Colombian manufacturing sector and its objective is to obtain basic information from the industrial sector, which would provide facts about its structure, characteristics and evolution. The data is collected annually and includes information from industrial establishments with ten or more employees, or a production value which is established annually. For example, for 2012 this value was $136.4 million in constant pesos (approximately US$ 45,000 as of today). The universe of the EAM consists of the total of industrial establishments which are operating in Colombia and are defined as Industrial, according to the International Standard Industrial Classification of All Economic Activities adapted to Colombia (ISIC Rev. 3)

On the other hand, the EDIT collect information of industrial firms according to the directory of establishments in the EAM and is performed every two-year. In contrast with EAM, the EDIT only collect information at firm level and it is performed at a different time. The pilot version of the survey was conducted in 1996. In this research, we use the following version of the survey: EDIT II (2003–2004), EDIT III (2005-2006), EDIT IV (2007-2008), EDIT IV (2009-2010) and EDIT VI (2011-2012). This survey takes as reference framework the conceptual guidelines from both the Oslo Manual and the Bogotá Manual. Its objective is to characterize the technological dynamics and innovation activities of manufacturing firms in Colombia, as well as carry out an assessment of policy instrument to the promotion and protection of innovation (Dane 2011). The survey is structured in six chapters that collect information on the innovation output and their impact on the firm; investment and financing of innovation; the personnel occupied by functional areas and educational level; knowledge flow and cooperation to innovate and finally intellectual property records, quality certifications, standards and technical regulations. Since the EDIT comes from the same universe as the EAM, they have common firm identifiers, which make possible to combine them for research purposes.

The access to these databases was difficult because the Colombian statistical office exerts strict statistical reserve regulation of firm-level data. Hence, the information could only be consulted directly at DANE's offices through the signing of a specific agreement of collaboration.

The research databases were subjected to a cleaning process before its use to correct for inconsistencies, missing values, and errors in the collection of information. In cleaning the database, several aspects have been considered:

- To establish the same units for the two surveys the procedure followed was collapsing the database of the EAM from establishment to firm level. This implied assign a unique ISIC code to multi-establishment companies. The criteria used was employ the sector with the greatest participation in the production of the firm.
- Data imputation using in the case of missing o zero values between two years for continuous variables such as valued added and sales.
- According to Lööf & eshmati (2006) and Raymon et al. (2010), it is excluded the firms with missing or zero values in any of the main variables of interest during the observation period. Among them are the sales, the value added and the firm`s personnel.
- To avoid possible distortions, in the case of the analysis of spillovers (Chapter 4 and 5), only was considered sectors and provinces with positive foreign investment in all year included. Also, only were included companies that have been observed in the database three years or more and with equal or more than 10 workers (Raymond et al., 2010).
- With the aim to control for the presence of outliers, the database excluded the firms with a growth rate in sales above than 250% or less than -40% (Mohnen et al., 2006).

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Appendix 2. Calculation of the Total Factor Productivity

The calculation of the Total Factor Productivity (TFP) is based on the methodology proposed by Levinsohn & Petrin (2003). This approach is an extension of the method proposed by Olley and Pakes (1992) which seek to corrects the endogeneity problems resultant of the correlation that exists between the unobserved productivity shocks and production inputs. To overcome this problem, the authors develop a model that uses the investment as a proxy of unobserved shocks. However, this method is not quite robust due there are firms with zero investment that generate truncation problems in the estimation.

Considering this problem, Levinsohn & Petrin (2003) proposed an estimator that uses the intermediate input variable as a proxy of productivity, arguing that the adjustment costs of raw materials demand are lower than investment ones, and it respond quickly to productivity shocks. In addition, in the data of productive performance surveys (EAM in Colombian case) usually there is more information about intermediate inputs compared to investment data.

The method assumes a logarithmic transformation of a Cobb-Douglas production function, which take the following form:

$$v_t = \beta_0 + \beta_l l_t + \beta_k k_t + \beta_m m_t + \omega_t + \eta_t \qquad (1)$$

where lower-case letters in Eq. (1) refer to natural logarithms, v_t is the firm's output, measured as valued added, l_t is labor input, k_t is the capital stock and m_t is the intermediate input. The firm's output is defined as valued added deflated by industry-specific producer price indices at the two-digit ISIC classification. The m_t variable was calculated using the consumption of raw materials deflated by the producer price index of the raw materials. The labor variable was built through two measures: (i) unqualified personnel corresponding to the blue-collar workers and operators, and 2) qualified personnel, defined as the sum of professionals, technicians and sales and administrative staff. The stock capital is defined as the value of fixed assets at the beginning of the year deflated by the simple average of the price deflators for terrains, buildings and structures, machinery and equipment, transport equipment and office equipment.

In the equation (1), the error term has two parts: (i) the transmission component of productivity (ω_t) and (ii) the term η_t, which is not correlated with the inputs. The first component is a state variable and, therefore, affects the decision rules of the firm in terms of the selection of the inputs. The demand for intermediate inputs m_t is determined based on the state variables of the firm, as follows:

$$m_t = m_t(k_t, \omega_t)$$

Given that m_t is a monotonic function growing in ω_t, the intermediate demand function can be reversed in such a way that ω_t can be written as a function of k_t and m_t:

$$\omega_t = \omega_t(k_t, m_t) \qquad (2)$$

Replacing the equation (2) into 1) it is possible to re-write the production function as:

$$\begin{aligned} v_t &= \beta_0 + \beta_l l_t + \beta_k k_t + \omega_t + \eta_t \\ &= \beta_l l_t + \phi_t(k_t, m_t) + \eta_t \end{aligned} \qquad (3)$$

where

$$\phi_t(k_t, m_t) = \beta_0 + \beta_k k_t + \omega_t(k_t, m_t)$$

Since the functional form of ω_t is not known, the coefficients of the production function cannot be estimated by the ordinary least squares method (OLS). Also, as the above equation is partly linear, it is necessary to use semi-parametric methods. Considering this, Levinsohn and Petrin propose estimate the model in two stages. In the first stage, is it estimated the coefficients for labor variables and of those factors different from the productivity proxy. Replacing a polynomial approximation of k_t and m_t instead of $\phi_t(k_t, m_t)$, it is possible to estimate the parameters using OLS, in the following way:

$$v_t = \delta_0 + \beta_l l_t + \sum_{i=0}^{3} \sum_{j=0}^{3-i} \delta_{ij} k_t^i m_t^j + \eta_t \quad (4)$$

This completes the first stage of estimation and produces estimators for β_l and ϕ_t (up to the intercepted since this is not separable from the first stage).

In the second stage, the coefficient of β_k it is estimated, beginning with the calculation of the estimated value of ϕ using the following expression:

$$\hat{\phi}_t = \hat{v}_t - \hat{\beta}_l l_t = \hat{\delta}_0 + \beta_l l_t + \sum_{i=0}^{3} \sum_{j=0}^{3-i} \hat{\delta}_{ij} k_t^i m_t^j - \hat{\beta}_l l_t \quad (5)$$

For any value of β_k^* it is possible to calculate a prediction for ω_t for all time periods using:

$$\widehat{\omega}_t = \hat{\phi}_t - \beta_k^* k_t \qquad (6)$$

Using these values, a consistent non-parametric approach to $E[\omega_t | \omega_{t-1}]$ is given by the regression predictions:

$$\widehat{\omega}_t = \gamma_0 + \gamma_1 \omega_{t-1} + \gamma_2 \omega_{t-1}^2 + \gamma_3 \omega_{t-1}^3 + \epsilon_t \qquad (7)$$

expression that Levinsohn and Petrin termed as $E\left[\omega_t \widehat{|\omega_{t-1}}\right]$. Given the values of $\hat{\beta}_l$, β_k^* and $E\left[\omega_t \widehat{|\omega_{t-1}}\right]$, it is possible to write the sample residue of the production function as:

$$\widehat{\eta_t + \xi_t} = v_t - \hat{\beta}_l l_t - \beta_k^* k_t - E\left[\omega_t \widehat{|\omega_{t-1}}\right] \quad (8)$$

Minimizing the square of the error, $\hat{\beta}_k$ can be obtained solving the following equation:

$$\min_{\beta_k^*} \sum_t \left(v_t - \hat{\beta}_l l_t - \beta_k^* k_t - E\left[\omega_t \widehat{|\omega_{t-1}}\right]\right)^2 \quad (9)$$

In this way, it is obtained the estimated parameters in the production function and it is calculated the prediction of productivity. Because of its logarithmic form, the predicted values for productivity take the following form:

$$\widehat{\omega}_t = exp\left(v_t - \hat{\beta}_l l_t - \hat{\beta}_k k_t\right) \qquad (10)$$